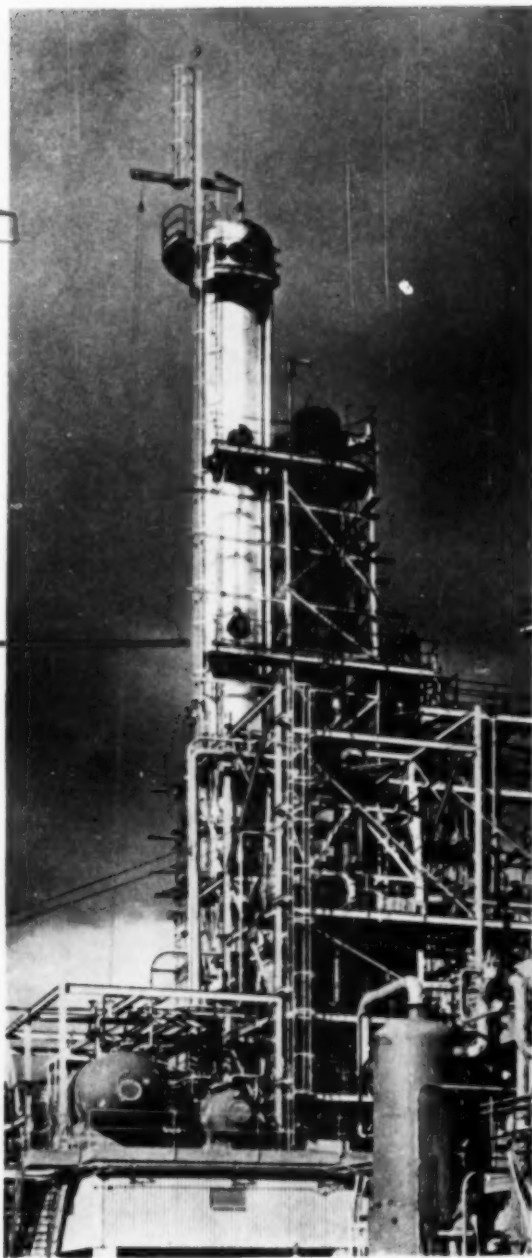# Chemical Engineering

Progress

Chemical Engineering Progress

FEBRUARY, 1954

Volume 50, No. 2

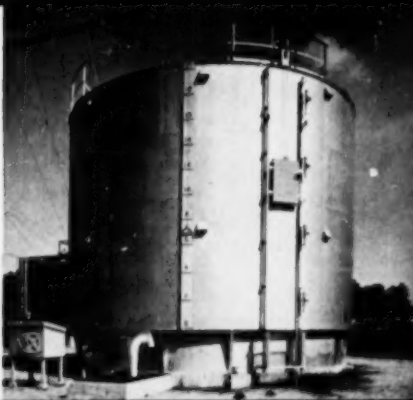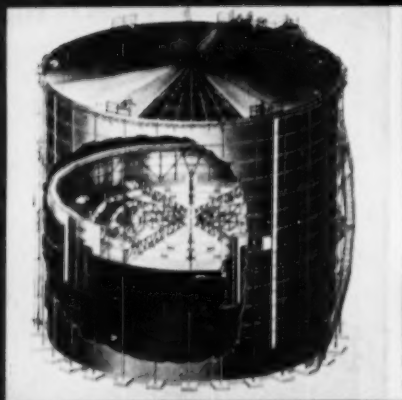Editor: F. J. Van Antwerpen

Advertising Manager: L. T. Dupree

The cover this month shows chemical engineering's latest additions to its line of aids to distillation and absorption; to the plates, bubble-caps, and trays comes the Turbogrid (see first article); to the saddles, rings, and spirals comes the Rosette (see second article). Both papers are from recent A.I.Ch.E. meetings: R. B. Olney, who discussed the Turbogrid at our St. Louis meeting, asked that his name not be carried as author "since at least 10 people have actively participated in presentation of paper."

LETTERS TO THE EDITOR

How Much Do You Make?

I refer to your footnote 15 on page 48 of the news section of the December, 1953, issue of *CEP*. You there answer a comment from the Tennessee Section that "Financial remuneration is not in line with other professions" by referring to a chart of an A.I.Ch.E. survey published in the August, 1952, *CEP*.

When I first saw this graph in 1952, I got a hearty laugh out of it, and never dreamed anyone, especially a chemical engineer, would be naive enough to take it seriously. Just imagine, chemical engineers making more money than doctors, than dentists—and lawyers—it's ridiculous!

My eye doctor charges $15.00 for a 15-minute visit and he is booked solid for two weeks ahead. That's a dollar a minute and many of his profession get more. Simple arithmetic will tell you he can easily clear $100,000 per year. Similar calculations will show you that dentists (in the city at least, where the poll was taken) earn $20,000—$30,000 per year, and ordinary physicians, $25,000 to $35,000 per year. And al! that for spending a couple extra years in school!

The mechanic who keeps my jalopy on the road earns about $7,000 per year counting overtime. According to *CEP* charts a chemical engineer does not reach that salary level until age 35. That means four years of schooling and 13-14 years of experience to catch up with the mechanic. Of course my poor mechanic friend had to struggle along with $3,000-$5,000/year for a few years before he reached his present status. And then look at the miserable predicament he is in. Unless he starts a business of his own, he will keep getting that lousy $7,000 a year, until of course, the general productivity of the nation is raised
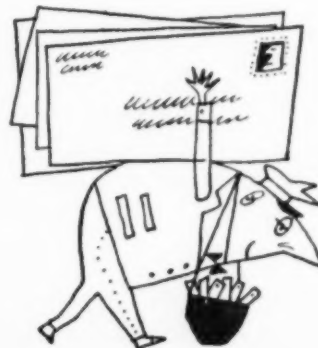
"NICHOLSON TRAPS PROVE THEMSELVES"

..in plant of one of Big 6 chemical firms

The importance of improving heat transfer efficiency in today's great processing plants increases as the proportion of critical applications grows and steam consumption mounts. The letter at the right is from one of the great chemical companies which have adopted Nicholson traps. Another of them recently reported that Nicholson traps were installed at one of their plants as part of a campaign to promote economical steam use. It resulted in a yearly saving of $500,000. See why an increasing number of leading plants are standardizing on Nicholsons.

CHEMICAL COMPANY

W. H. Nicholson & Co.
Wilkes-Barre, Pa.

Gentlemen:

Your representative, Mr. _____, said he believed you would appreciate it if we would send along to you the following information on Nicholson steam traps used in our plant.

We use above traps for processing and heating. We have previously used ____, ____ and ____ traps. Some of these are still in use. However, Nicholson traps have proved themselves in our plant. We do not have a record of our saving in heat-up time and increased production.

Yours very truly,

Signature Deleted

Send for TRAP CATALOG 953

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PLANT USE

LETTERS TO THE EDITOR

through the efforts of those self-seeking overpaid engineers.

JAMES N. ADEMINO
Bryn Mawr, Pa.

[Figures on chemical engineers' earnings were released by Bureau of Labor Statistics.—Ed.]

A Plea for the Small College

We are approaching a serious and not generally appreciated crisis in engineering education in this country, with industry not supporting technical education sufficiently, nor is present support applied everywhere where it will do the most good. It is generally recognized that today it is much more difficult for a small business to survive and prosper than at almost any time in our history. That this is patently applicable in the field of Education, is not generally recognized. Engineering is one of the most expensive undergraduate fields to teach. Our prestige-conscious public, other things being equal, as individuals would rather go to a large "name" school than to a smaller one. Oberlin and Reed have proven that science, at least, can be taught just as well in a small school as anywhere. I believe that this could be true in engineering too. However, the natural result is that all things gravitate toward larger schools with snow-balling effect. Better faculties, equipment, more students, grants, scholarships, donations, etc., at first drift, then move more swiftly in the established paths. Even donors feel more kindly toward multimillion dollar "Monster-Tech," purely from the prestige aspect; from the fact that many others are giving to that school. He feels that his money is wasted in being given to "Small College."

This matter can be resolved by asking: "Do we want fewer and larger schools of engineering, or, remembering that once all things were small, do we want to help our smaller schools also to grow?" This question is very much akin to the current furor over increasing Federal power—call it, "Socialist Big Government." Or, looking at it the other way, compare the government's anti-trust activities. The only way that small schools can compete is to offer comparable faculty salaries, and to have comparable facilities to offer the student.

Those institutions which rely entirely, or principally, upon tuition for their income are hopelessly outmatched by state-supported schools whose principal income stems from taxation. That they cannot long survive and do a real job in teaching engineering is obvious.

LETTERS TO THE EDITOR

The crisis I speak of is the combination of this effect with an increasing tendency to direct financial support exclusively at the graduate level. During the academic year of 1952-53, numerous graduate fellowships went begging. We must realize that without *undergraduate* training, we have no graduate students. The shortage of engineers in industry has pushed starting salaries to the point where graduate work is less interesting financially than ever before. It seems to me that a more widespread support of undergraduate engineering education is even more essential than to expand that given to graduate research. Further, under proper supervision, a great deal of work of a very respectable caliber can be accomplished through the undergraduate thesis. The subsidation of faculty salaries is one very concrete step toward real progress, and can be accomplished in various ways.

In Chemical Engineering, at least, it seems to me that we are acquiring a top-heavy academic structure, gravitating toward the large state and few independent universities.

Yet, "the great glory of America's privately supported colleges and universities lies in their independence. It is independence that enables them to serve all men, not merely a few; which assures us of research and learning, free from bias and directed toward a single goal: the discovery of truth and knowledge made available to all. This is truly free enterprise in education. It is through such free enterprise that our civilization has its best hopes for survival and advancement." *

GEORGE C. SZEGO

Seattle University,
Seattle, Washington

His Master's Words!

The Annual Thesis Index published in the January issue of *CEP* is an excellent idea. However, I think it ought to be extended to include a yearly compilation of the Master's theses in chemical engineering, and if this is too lengthy for publication, it should be published in mimeograph form and distributed gratis to the members. This could be something like the Chemical Engineering Faculties bulletin prepared by the Chemical Engineering Education Projects Committee. A great deal of interesting research is being done at the M.S. level and it might be of help to chemical engineers generally.

STANLEY GROSSEL

The Barrett Division
Allied Chemical & Dye Corp.
Philadelphia, Pa.

* J. L. Hain (Johns Hopkins University Alumni Magazine).

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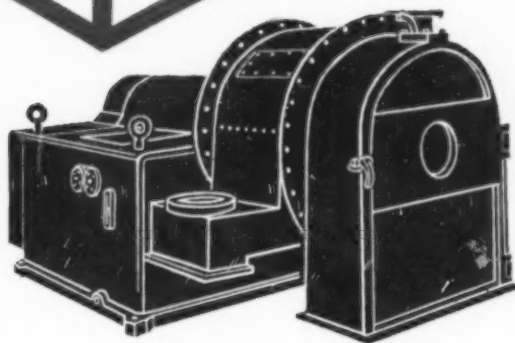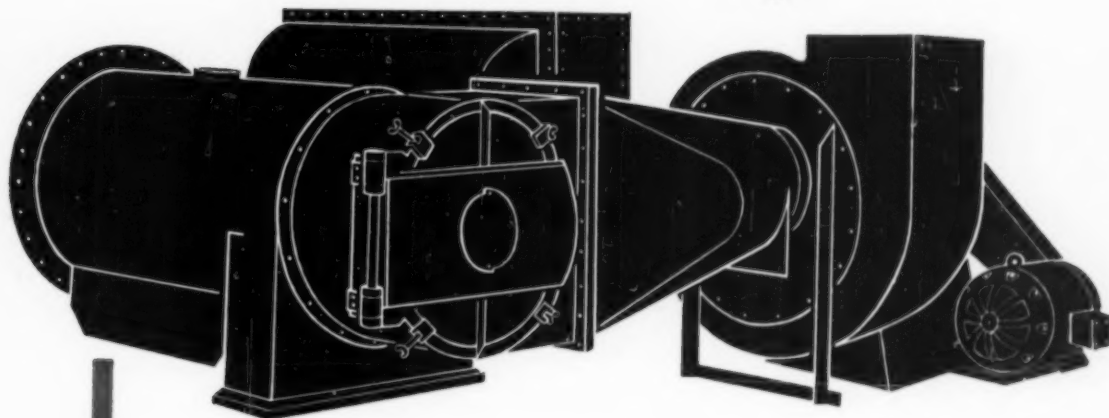
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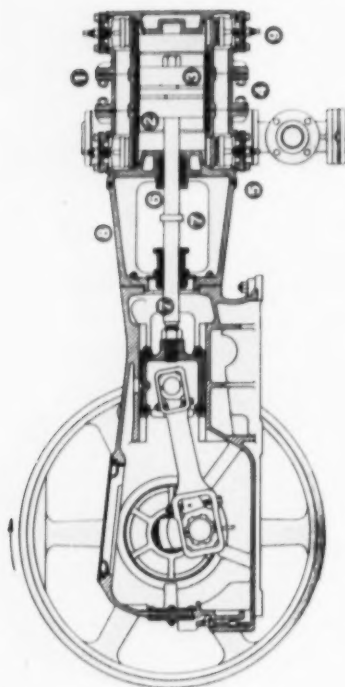
NOTED AND QUOTED

The Right to Think

The claim of academic freedom is based on the high and serious calling of the academic profession. That calling is to think. A university is a center of independent thought. Since it is a center of thought, and of independent thought, it is also a center of criticism. The freedom of the modern university in a democratic society is not based on the remnants of a medieval tradition, but on the proposition that societies require centers of independent thought and criticism if they are to progress, or even to survive. Academic freedom means that the independence of the thought that goes on in a university is so important to society that a man cannot be restrained or punished by those who pay him because he holds views with which those who pay him disagree . . . .

Robert M. Hutchins
In "The University of Utopia"

The Genius in Your Midst

It has long been realized that one of the most effective ways to ensure outstanding achievements in fundamental research is to locate the individual of genius and support him liberally as he pursues his own way. . . . We need genius, of course. But there are geniuses who are utterly lone workers, who are lacking in generosity and unduly jealous of their reputations, who will retire into a cubicle and work with no man. Great things have been accomplished by such individuals in the past and will be in the future. But much more has been and will be accomplished by those who have brilliant creative skills combined with human attributes that make them always welcome in a community of their peers. Their full accomplishment may not appear in their own papers, for they will be surrounded by devoted disciples, and their creative contribution will be in men as well as in direct results. . . .

The other part of the problem of supporting genius is to find the genius before he has matured and made a reputation; for otherwise, changing his environment at best merely gives him a wider opportunity and at worst is a form of piracy.

Vannevar Bush
Carnegie Institution of Washington

The Engineering Interne

I wonder whether the tempo of accumulating technical knowledge in many of our industries does not call for something resembling an overlap between education and paid employment rather than the present end-to-end anastomosis. . . . It seems to me that industry could explore still further the possibilities of an equivalent of the interneship, especially the metallurgical, chemical, electrical, and pharmaceutical industries. . . .

It is an immense advantage to any institution to be on the River of Youth. When young men and women are flowing through an institution, you have a chance to choose what you want from among those whom you know directly and, if you want, intimately. Besides that advantage, the young men and women stimulate their elders—and have even on occasion been known to inform them.

Alan Gregg, M.D.
Vice President, The Rockefeller Foundation

As the British See Us

Awareness
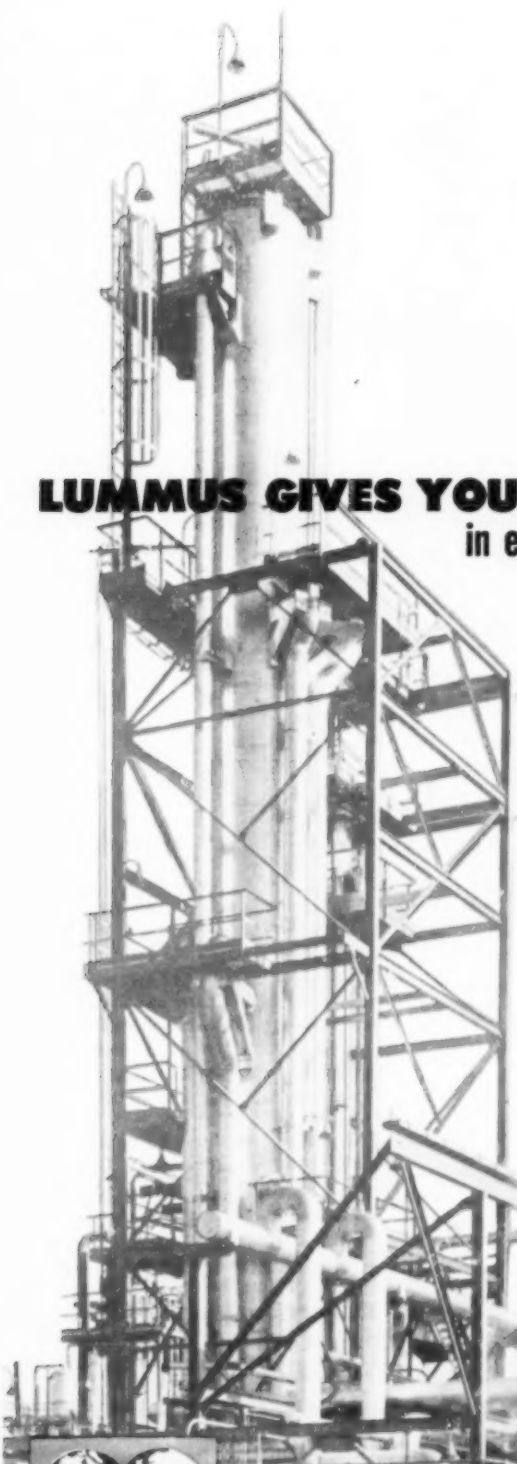
In 1949 two thirds of the world production of synthetic organic products were made in the United States, 8 million tons out of 12 million. For this three advantages which America has enjoyed are partly responsible—her vast home market with free competition, the effects of two world wars when she was outside the theatre of operations, and her superior natural resources of oil and natural gas and of materials like sulphur and phosphate rock. But there are other reasons, and of these the Mission [O.E.E.C.] emphasizes that a large part of the American success in industrial chemistry is due to the efficiency of her chemical engineers and of the schools in which they are trained. . . .

. . . the Mission was impressed by the progressive attitude of the American people and their talent for developing and applying quickly the result of research to large-scale operation. There is a faith and belief in chemical engineering in America, an awareness that is lacking in Britain.

. . . We need more chemical engineers and more schools of chemical engineering in our universities and technical colleges. We need chemical engineering construction companies with resources more nearly equal to those across the Atlantic so as to secure design and construction contracts in the world market. We need more financial support

for chemical engineering research both in the universities and technical colleges, and in a specialized laboratory with support from Government and industry, as was envisioned in the Cremer Report. But above all, we need a more general recognition of the part that chemical engineering is bound to play in modern industry: otherwise, we shall not secure quickly the priorities of finance and building needed for these three vital developments.

Sir Harold Hartley
Chemical Engineering Conference
London, England

Application

It is no accident that the enormous growth of American production has coincided with an increasing representation in management of men with a strong scientific or technical background. It cannot be too strongly emphasised that unbalanced boards of management, on which technical representation is small or non-existent, are unlikely to be able—even if they were not limited in other ways—to take full advantage of the results of scientific research . . . .

Sixth Annual Report of the
Advisory Council on Scientific Policy
London, England

It's the Little Man in America

In addition to the various kinds of governmental restrictions employed abroad, reference should also be made to the use of cartels in foreign countries, and to the high degree of concentration of the chemical industry among a few companies. For example, in the United Kingdom, two companies control 85% of the production of organic chemicals; in France, two companies produce 95% of its out put of these materials; in Italy, two firms account for 80% of capacity; in Western Germany, four companies produce substantially all the chemicals. By contrast, sales of the 3 largest American chemical companies amount to only about 15% of aggregate domestic chemical industry sales.

Charles S. Munson & William C. Foster
Manufacturing Chemists' Association, Inc.

Volunteers Not Wanted

Executive responsibility comes later in life, almost wholly as a result of the office seeking the man, and often as a complete surprise. That is as it should be, for while there are always volunteers for better jobs, the raised hand is rarely a satisfactory guide.

Crawford Greenewalt
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HEAT is one of man's most useful servants. With it, he can separate gasoline from crude oil . . . cook food . . . generate electricity . . . refine steel from raw ore and roll it into mile-long sheets. But to do these and countless other jobs, heat must be applied in the correct amounts . . . to obtain critical temperature values.

Forward-looking research and production men realized some years ago that "rule of thumb" was entirely inadequate for replacing complex processes. They needed facts obtainable only from automatic measurement . . . performance possible only through automatic control.

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With *Pyr-O-Vane* instruments you can have electric control of either the two-position, three-position or time-proportioning types.

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the most versatile of temperature elements, are supplied for ranges from −300 to +2800 F

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are recommended for highest accuracy from sub zero to 300 F and for narrow spans

Radiamatic

(radiation-type) elements are applicable to direct measurement of work temperature . . . to moving objects . . . to extremely high . . . and other jobs impossible for any other element
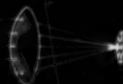
thermometer bulbs

rugged, sensitive elements for moderate temperatures

Opinion and comment

THE CLASH OF SYMBOLS

Editors have a lovely life. One Friday morning in January, with about a dozen other editors from the scientific, engineering, and mathematics press, we spent several hours being unhappy about Greek letters. After several thousand years, while there is no doubt that the Greeks had a word for it, there is a suspicion that they didn't have a letter.

The gist of the session was an attempt of the American Standards Association to have accepted as standard a new type arrangement of Greek letters. Nothing radical was attempted; the letters are still the Porson Greek used in C.E.P., for all practical purposes the only satisfactory Greek font available to the technical press.

The trouble those Greek letters cause!

We on C.E.P. have been unhappy for several years about the style of the letters and as a minimum recommended to the conference a complete redesign of Porson Greek to harmonize with modern type faces. Other editors expressed their dissatisfaction with the size of the letters and their disturbing effect in a line of type. As a matter of logic we then recommended that the professions abandon Greek in their writings. The howl disturbed Socrates (in more ways than one), and our suggestion was defeated on the grounds that Greek has always etc., etc. been used. The arguments are familiar, and while we have no serious hope that Greek will be abandoned, we believe that there is merit in our suggestion.

Think it through.

Why do we use Greek symbols? Only because these letters were at the time easy for the learned to use. Today most of us are introduced to Greek only when a professor in mathematics or in physical chemistry begins to search for symbols as he demonstrates a problem on the board. He writes the letters imperfectly on the board, and forever afterward they cause trouble to the engineer, who seldom bothers to look up the Greek alphabet and certainly never learns to recognize Greek letters or write them.

As publishers, we have our problems. Does the man mean alpha (α) or does he mean small a? Is this a kappa (κ) or is it a vector κ? What engineer can write a zeta (ζ), can identify xi (ξ), or knows that there are three forms of phi, sigma, and theta?

We confess right now that we have been even more guilty than most in confusing the issue. Far from using our standard in the Greek letters, we have at times varied our typeface on the theory that as long as the symbol is explained in the notation, it matters little whether α is alpha, or italic a.

That brings us to two points. First, more symbols for the scientists, be they mathematicians, engineers, or chemists. We have a number of beautiful symbols already available in type, and though this editorial has been whimsical till now, we offer these with the hope that they may encourage a greater familiarity with the available symbols.

For instance, a symbol easily written is a geometric form enclosing a letter. We have a group borrowed from the timetable. Why could not Ⓕ and Ⓣ be interior or subsidiary quantities instead of the F_1, T_1 and F_1^2 which we now use? What a beautiful compound dimensionless number ₮ would make—the Malayan symbol for money. Other monetary figures such as the peseta ₱ are available.

Did we originally borrow the integral sign $\int$ from the musical symbol for repeat 𝄆? If so, why not use other figures such as hold ⌒, sharp ♯ and double sharp 𝄪?

There are fonts of letters and numerals in boxes ⑥, half boxes, ① in semicircles, and in triangles △. We can borrow from the meteorologist various forms such as ⊕ meaning overcast; from the astronomer ⚹, which means quincunx; ⚺, which means semi-sextile; and ♓, which is Pisces.

And when we run out of these, we still have the International Phonetic Alphabet with a series of letters like ŋ, ç, ʈ, and i. Finally after a lengthy study of symbols it becomes ◗ —partly cloudy.

Turbogrid Distillation Trays
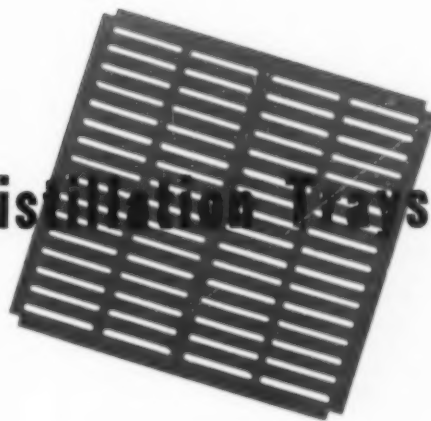
Engineering Staff
Shell Development Company, Emeryville, California

Turbogrid trays, a new type of vapor-liquid contacting tray, were introduced to industry about a year ago as the result of an extensive research program on distillation equipment within the Shell companies. The design, simple in construction, achieves high capacity, low pressure drop, low liquid holdup, and low cost relative to conventional designs; the separation as theoretical trays per foot of column height, is about the same as for conventional designs but is effected at higher throughput. This design has been successfully applied in essentially all types of service and now Shell has about fifty grid-tray towers in operation with more under construction.

Variables entering into the selection of optimum Turbogrid design are discussed qualitatively. Performance test results obtained in several Turbogrid plant columns are compared to test data obtained with bubble-cap trays or packed

sections; columns in light hydrocarbon service, chemical plants, and gas-treating service are included.

New applications of Turbogrid trays, other than conventional fractionation service are discussed; these include deentrainment sections above vacuum flashers or steam boilers; condensing or vaporizing sections, including direct quench exchangers; and residue strippers and slurry sections.

Description of Equipment

Turbogrid trays consist of a flat grid of parallel slots, the grid extending over the entire cross-sectional area of a column except for the area blocked by support structure. The slots can be either stamped perforations in a flat metal plate or may consist of the spaces between parallel bars. Figure 1 illustrates a typical Turbogrid tray of the parallel-bar-type construction ready for installation; the view is of the top tray surface and represents the tray essentially as it will appear when installed

Table 1.—Performance of Turbogrid Trays in Gasoline Fractionation, Column No. 1

Stamped Plate-Type Trays, 12-in. Tray Spacing, 5-ft. diam. 19 Rectifying Trays, 21 Stripping Trays

	Feedstock No. 1 (full boiling range straight run gasoline)				Feedstock No. 2 (prefractionated straight run gasoline bottoms)			
Run number	1	2	3	4	5	6	7	8
Flow bbl./day feed	5300	6400	5720	4384	6000	5750	5700	5410
Tops	4100	5100	2840	3400	4350	2100	2250	2630
Bottoms	1200	1300	2880	984	1650	3650	3450	2780
Internal reflux/feed	0.522	0.332	0.627	0.358	0.472	0.686	0.491	0.343
IBP bottoms — end point tops	28	—5	26	10	—22	10	16	12
°API feed	59.2	61.5	58.0	59.4	50.8	51.5	51.3	51.2
Tops	62.7	66.1	67.0	63.6	53.5	58.4	58.1	57.2
Bottoms	46.8	46.8	48.0	45.3	44.8	48.2	48.2	47.9
Per cent design rates	137	132	101	96	145	128	110	91

in the column. The trays are normally installed without downcomers for liquid flow; they can, however, be utilized with downcomers if desired. Installation with downcomers is usually not recommended inasmuch as the downcomer area cannot be utilized for vapor flow and consequently a greater column diameter may be required.

In normal operation of Turbogrid trays, the parallel slots in the trays serve as the passages for both liquid and vapor flow through the tray. The flow of both liquid and vapor occurs as a cycling or intermittent jet action, uniformly distributed with respect to both phase flows over the entire grid pattern. The interference of the countercurrent flow of liquid and vapor through the tray results in a buildup of liquid on the tray, the liquid holdup being approximately equal to the tray pressure drop. When grid trays are installed with downcomers they perform similarly to conventional perforated trays with downcomers.

Significant variables influencing the selection of a Turbogrid design are the stream properties and rates, the structural details of the tray layout and the specific requirements of the particular separation process. Structural details that can be varied to meet the flow or process requirements are the open-slot area in the tray, the slot width, the bar shape and tray spacing. It has been found possible to standardize on a rectangular bar shape for most applications, although other shapes frequently are recommended for certain conditions. The open area is selected to provide the optimum economic balance between tray capacity and efficiency; a large open area gives highest capacity but at some sacrifice in tray efficiency and operating range. Other factors, such as pressure-drop limitations, will also affect the selection of the tray free area. In some cases holdup requirements will dictate the structural design of the trays. Where tolerance to corrosion or fouling is desired, slot width, and to a lesser extent bar shape, become factors to be considered. The tray spacing selected represents a compromise between the factors of tray accessibility, and the relative importance of column height and diameter. Tray spacings of 12 to 18 in. normally are used in Turbogrid installations, with 18-in. tray spacing being preferred in large columns to improve tray accessibility.

The performance of grid trays relative to bubble-cap trays in experimental test columns has been summarized in a previous paper (1). The comparisons given at that time showed that these trays have 20 to 100% greater capacity than bubble-cap trays, approximately the same separation efficiency per foot of tower height and 40 to 80% lower pressure drop. In addition, relative Turbogrid bubble-cap-tray-cost data were

cited. This earlier summary is substantiated at this time by a discussion of results obtained in operation of plant column installations. Also additional construction cost data permit a more complete cost comparison of the two tray types and in addition, specialized applications of Turbogrid trays are described in detail.

Plant Performance of Turbogrid Columns

Twelve examples of Turbogrid-tray installations in plant service have been selected from the fifty-odd grid towers now in service to illustrate the performance under actual operating conditions. These examples cover a wide range of temperature and pressure and include applications pertinent by comparison to most uses considered for grid trays. Of the twelve columns, five are in hydrocarbon fractionation service and the remainder are in a variety of other applications.
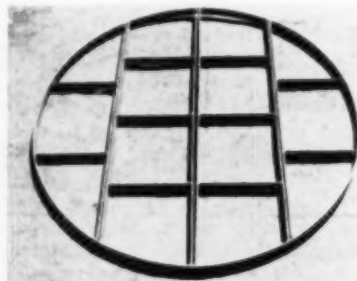
Structural framework for grid trays (framework cut into four sections in final assembly).
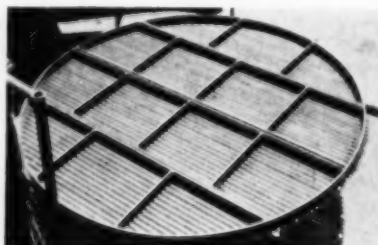
Bottom side of partly completed tray (welding and trimming of bars and sectioning of tray incomplete).
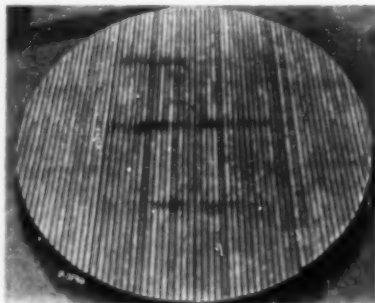
Top side of completed tray.

Fig. 1. Typical layout of grid trays.

HYDROCARBON FRACTIONATION

Of the five installations of Turbogrid trays in hydrocarbon fractionation to be discussed, four columns are normal installations of Turbogrid trays, while the fifth is an installation with liquid downcomers. One of the installations used trays of the stamped-plate type, and the remainder used bar-type tray construction. All the installations performed equal to or better than design, and exceeded bubble-cap tray capacity and efficiency for cases where comparative data were available.

Column No. 1 in hydrocarbon service is 5 ft. in diam. with forty grid trays of the stamped-plate type installed at 12-in. tray spacing. The column has nineteen rectifying and twenty-one stripping trays. The installation was designed to operate in a number of different services and this flexibility in performance has been substantiated in test runs. The Turbogrid trays replaced bubble-cap trays which were limited in capacity and separation; however, other plant changes concurrent with the Turbogrid-tray replacement preclude an exact comparison with the original bubble-cap column in this case. Table 1 summarizes the rate and performance data at 15 lb./sq.in. gauge for operation of Column No. 1 with grid trays installed with two different feedstocks. Feedstock No. 1 was a full boiling range straight run gasoline and Feedstock No. 2 was prefractionated straight run gasoline bottoms. Representative feed, tops and bottoms A.S.T.M. distillation curves are shown in Figure 2 for Runs No. 3 and 7 for Feedstocks 1 and 2, respectively. Figure 3 illustrates the separation achieved with both feedstocks, measured as initial boiling point of bottoms minus end point of the tops, as a function of the percentage of design rates and the internal reflux to feed ratio. Data show that design separation was significantly exceeded at design flows and reflux and that performance was still satisfactory for rates corresponding to 120% design rates. It is seen, furthermore, that design separation can be expected for rates as low as 60% of design, indicating a two-fold operating range in this service while meeting product specifications. The column has also performed satisfactorily as a pressure distillate stabilizer and as a debutanizer.

Calculated bubble-tray capacities for well-designed bubble-cap trays for the test rates show that at 18-in. tray spacing, the bubble-cap trays in the original installation would be overloaded except for test runs 4 and 8, with calculated downcomer backup of clear liquid equaling or exceeding the tray spacing for runs 1, 2, 5 and 6.

Test Run No. 3
Feedstock No. 1

Test Run No. 7
Feedstock No. 2

% Distilled
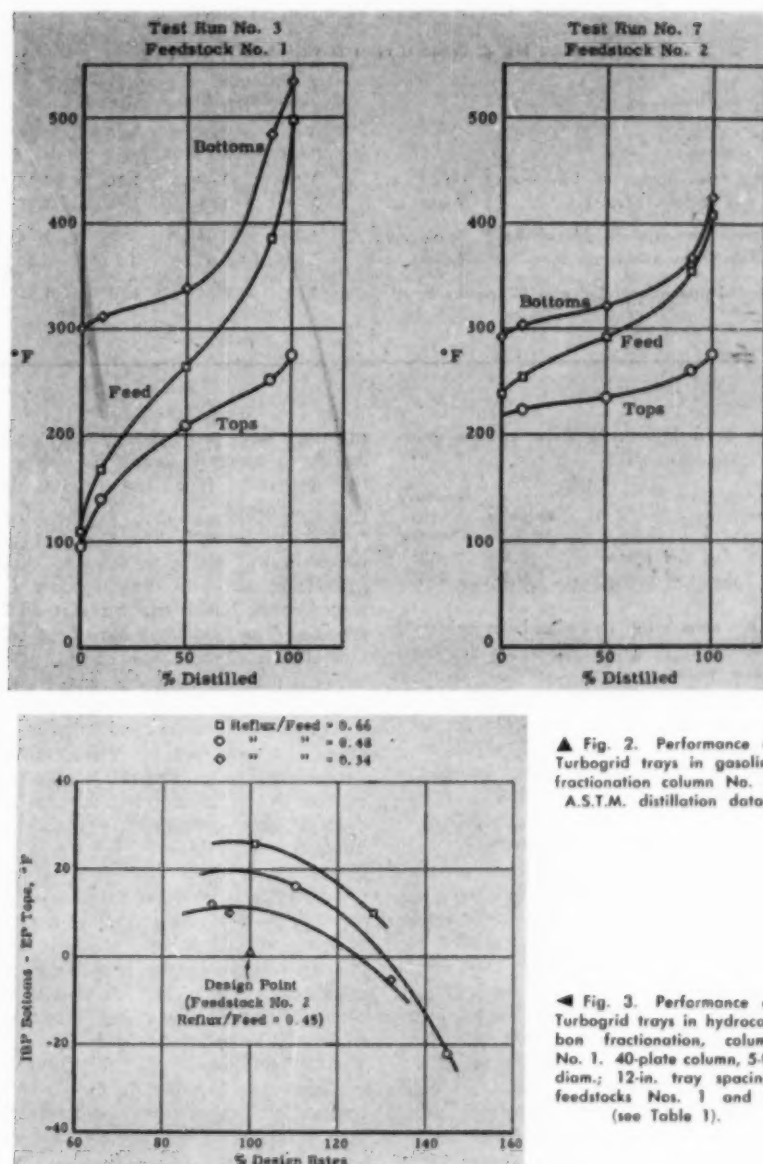
% Distilled

▲ Fig. 2. Performance of Turbogrid trays in gasoline fractionation column No. 1. A.S.T.M. distillation data.

□ Reflux/Feed = 0.66
○ " " = 0.48
◇ " " = 0.34

Design Point
(Feedstock No. 2
Reflux/Feed = 0.45)

% Design Rates

◄ Fig. 3. Performance of Turbogrid trays in hydrocarbon fractionation, column No. 1. 40-plate column, 5-ft. diam.; 12-in. tray spacing, feedstocks Nos. 1 and 2 (see Table 1).

Table 2.—Performance of Turbogrid Trays in Deethanization

Turbogrid trays—19 rectifying, 11 stripping, 12-in. tray spacing
Bubble-cap trays—13 rectifying, 9 stripping, 16-in. and 24-in. tray spacing
Feed rate 4,800 bbl./day; Reflux rate 2,000 bbl./day

Component	% Recovery in Tops		% Recovery in Bottoms	
	Bubble Cap	Turbogrid	Bubble Cap	Turbogrid
$C_2^=$	59	66	..	..
C_2	49	45	..	..
$C_3^=$	..	..	95	95
C_3	..	..	97	98

Table A

Flow Rates bbl./day		Rectifying Section		Stripping Section	
Feed	Reflux	% Capacity	Tray Efficiency, %	Capacity %	Efficiency, % Tray
7,300	2,200	28	26	30	44
10,380	2,660	39	40	64	62

Column No. 2 is in deethanizer service. This column consists of two swedged sections, 4 ft. in diam. in the rectifying section and 5 ft. in diam. in the stripping section. The grid-tray installation has 19 rectifying and 11 stripping trays at 12-in. tray spacing, and the bubble-cap installation that was replaced had 13 rectifying trays at 16-in. tray spacing and 9 stripping trays at 24-in. tray spacing. The grid trays are of the bar-type construction.

The column is used to fractionate a feed consisting primarily of C_2's and C_3's. The principal function of the column is not strictly deethanization but rather production of a top product containing small amounts of C_3's. The original bubble-cap column performed satisfactorily at a feed rate of 4,950 bbl./day and 500 lb./sq.in.abs. to give 96.8% propylene recovery in the bottoms and 48.8% of C_2's going to tops. However, at higher feed rates the column would not operate satisfactorily unless the reflux rate was reduced, thus adversely affecting the separation. In addition, the bubble-cap column would not perform satisfactorily with a feed containing a high percentage of C_2's. The Turbogrid installation will operate with desired reflux and separation for the average feed rate now required of 6,000 to 6,500 bbl./day and can also handle the maximum feed rate of 7,400 bbl./day if necessary.

Comparative bubble-cap tray Turbogrid-tray performance is summarized in Table 2 for flow rates that could still be handled satisfactorily by the bubble-cap column. It is seen that the grid-tray installation provides separation equal to the bubble-cap tray at flow rates close to the maximum for the latter. The separation shown is maintained at feed rates of 7,400 bbl./day for the grid-tray installation, and in the case of the bubble-cap tray it deteriorates rapidly for feed rates in excess of 5,000 bbl./day.

Column No. 3 in hydrocarbon fractionation is in the stripping section of a 5-ft. diam. depropanizer column operating at 230 lb./sq.in. gauge. In this installation, 19 Turbogrid trays (15 at 12-in. tray spacing, 4 at 18-in. tray spacing) replaced 14 bubble-cap trays at 18-in. tray spacing. The circumstance requiring the change from bubble cap to Turbogrid trays was not in this case one of capacity or separation limitation with the bubble-cap installation. A routine column inspection had indicated the bubble-cap trays to be badly corroded with tray failure and consequent poor performance incipient; bubble-cap tray replacement could not be obtained in the requisite time, while grid trays were designed, fabricated and installed within six working days.

The performance of the column was improved by the installation of grid trays in the stripping section. Comparative recoveries before and after the change, for normal feed and reflux rates, were:

	Bubble-Cap Trays %	Turbogrid Trays in Stripping Section %
Propane recovery in tops	98.9	99.3
Butane recovery in bottoms	97.7	98.2

The Turbogrid trays gave satisfactory separation for feed rates from 1,900 to 4,900 bbl./day, and did not flood at the latter rates (calculated at 80% capacity). Test-run data gave a calculated grid-tray efficiency of at least 60% at 2,540 bbl./day feed and 2,890 bbl./day reflux, based on the key components propane and isobutane; the low-propane content in the bottoms precluded a more exact efficiency determination than that stated.

The fourth column with Turbogrid trays in hydrocarbon service reviewed at this time is in debutanization operation. The grid-tray installation had twenty rectifying trays and fourteen stripping trays at 18-in. tray spacing in the 6-ft. diam. column and represented a tray-for-tray replacement of the original bubble-cap trays. This grid installation has not been operated at high capacity because of condenser and feed supply limitations. The tray efficiency of this column at low feed rates is summarized in Table A. Ordinarily, use of Turbogrid trays at 25 to 40% of capacity is not recommended; the separation achieved in this column at low rates, however, has been satisfactory and the tray efficiencies obtained in the test runs were substantially in agreement with those used in the design procedure for grid trays.

The last example of Turbogrid trays in hydrocarbon service, Column No. 5, features the only plant installation using trays with downcomers. In this column, a deethanizer, 16 grid trays replaced an equal number of bubble-cap trays at 24-in. and 30-in. spacing in the stripping section; the purpose of the installation was to increase column capacity. The installation with downcomers was chosen in order to avoid mechanical difficulties attendant on removal of downcomers welded to the column shell. Performance of the installation has been satisfactory for rates 25% in excess of those limiting bubble-cap-tray operation and no loss in separation has been experienced. The separation achieved in the original bubble-cap-tray installation under near capacity conditions, which

has been duplicated or bettered in grid-tray operation is:

	Recovery in Tops	Recovery in Bottoms
C_3's and lighter	98.8	1.2
C_3's and heavier	10.3	89.7

This separation has also been achieved in the Turbogrid installation for feed rates as low as 75% of the attainable bubble-cap rates. The actual column capacity with grid trays has not yet been reached and is estimated to be 35% greater than the limiting bubble-cap rates.

Nonhydrocarbon Applications

Turbogrid trays have been installed in a considerable number of stripping, absorption and distillation services, largely in chemical plant operation. In these operations grid trays have exhibited, in addition to capacity and separation advantages, less tendency toward fouling and corrosion than with bubble-cap trays. This group of installations also affords additional comparative operating data between Turbogrid trays and other types of vapor-liquid contact equipment. The performance of seven columns or applications will be covered.

Plant application No. 6, in which Turbogrid trays have replaced bubble-cap trays in a total of five columns and have been installed initially in two other columns, involves the stripping of alcohols from fat hydrolysis acid with steam. Grid trays have shown a distinct advantage over bubble-cap columns in this type of operation. Up to 50% increase in capacity over bubble-cap trays has been realized with increased tray life and reduced tendency for deposition of fouling materials. Alcohol yields have been maintained or bettered and product concentration equaled. Tray life has been doubled, from ten to twelve months with bubble-cap trays, and eighteen to twenty-four months with grid trays. Where bubble-

cap trays have plugged in three to four months, grid trays have shown only a thin deposit of fouling material in this length of time.

In a representative Turbogrid installation in this stripping service, seven grid trays at 24-in. tray spacing replaced seven bubble-cap trays at 28-in. spacing. The grid trays have been successfully fabricated from copper (the material used for the bubble-cap trays), Karbate, cupronickel or Corrosiron and represent bar-type tray construction or milled-slot construction. The performance of two different grid installations relative to bubble-cap trays, column layouts as just indicated, is shown in Table 3.

Operation in Run No. 4 is at the preferred capacity level for Turbogrid trays. For this run, stripping is more complete and alcohol production is 50% greater relative to the bubble-cap-tray installations. Run No. 3 shows the comparative operation closer to capacity, while still retaining an acceptable level of tray operation.

Application No. 7 is in the purification of a gas stream, predominantly hydrogen, having benzene as an undesirable impurity. Reduction of benzene from 350 p.p.m. to ~1 p.p.m. is required to eliminate freezing-out at a later process point. This absorption operation had been carried out previously in a 32-in. column equipped with 16 bubble-cap trays at 18-in. tray spacing. However, capacity limitations occurred at high gas flows entailing decreased absorber oil rates with consequent decreased absorption. In addition, fouling occurred frequently with the bubble-cap tray, further reducing the capacity and separation. The replacement grid-tray installation had forty-eight trays at 6-in. spacing, and used wide slots and fairly high open area to reduce fouling. A basket-type installation was employed, in which all of the trays were bolted together and installed in the column as a single unit.

Table 3.—Performance of Turbogrid Trays

Application No. 6, Chemical Plant Service—Alcohol Stripping

		Turbogrid Installation A		Turbogrid Installation B	
		Run No. 1	Run No. 2	Run No. 3	Run No. 4
Flow rates relative to bubble-cap tray capacities rates	Liquid	1.46	1.40	1.51	1.35
	Vapor	1.44	1.51	1.73	1.51
Stream compositions of alcohol, relative to bubble-cap tray	Tops	1.09	1.04	0.99	1.04
	Bottoms	1.6	0.4	0.0	0.0
Alcohol production relative to bubble-cap tray		1.53	1.46	1.74	1.51

and other acidics from a $C_3 - C_3 =$ gas stream, using dilute caustic as a scrubbing medium. The grid-tray installation has fourteen trays at 12-in. tray spacing and was installed as a replacement for an equal height of Raschig-ring packing. The capacity of the installation is at least 35% greater than the packed section, the pressure loss is much lower and the scrubbing efficiency is higher. At normal gas rates, corresponding to 65% of grid-tray capacity, the operating results are as shown in Table B.

Table B

Installation	% Removal of acidics	Column pressure drop, lb./sq. in.
Packed section	98.1	10.0
Turbogrids	99.2	1.2

A survey of plant operating data with packed columns in this service showed that the gas was not consistently neutral and that trouble was frequently encountered in Raschig-ring breakage and subsequent channeling of flows. The effluent gas from the Turbogrid installation has been consistently neutral.

Prior to the replacement of the packed section with Turbogrid trays a commercial gas scrubber was tested in this service and gave much poorer performance than either the packed column or the Turbogrid trays.

Column No. 9, illustrating Turbogrid trays in general vapor-liquid contacting, is a 6-ft. diam. column stripping hydrogen sulfide, carbon dioxide, ammonia, phenol and other impurities from refinery sour water, using steam as a stripping medium. The sour water ordinarily contains about 3,200 p.p.m. H_2S, 3,400 p.p.m. NH_3 and 1,300 p.p.m. CO_2. The grid-tray installation, fourteen trays at 18-in. tray spacing, takes the place of eight bubble-cap trays at twenty-four-in. tray spacing. The operation of the grid trays is approximately equivalent to that of the bubble-cap trays as shown below. The Turbogrid-tray installation at the above rates was operating at a low fraction of capacity (40%) so that substantially better stripping is expected at higher flow rates, which will occur after refinery expansion. The

Fig. 4. Performance of Turbogrid trays. Application No. 7, benzene absorption.

Performance of the Turbogrid trays and the bubble-cap trays is summarized at a constant oil : gas ratio in Figure 4, which shows the residual benzene and naphthalene in the exit gas as a function of the column throughput. The data show that the grid trays perform better than the bubble-cap trays at high throughputs where the bubble-cap trays, because of capacity limitations, are starting to show poorer separation. At low throughputs the bubble-cap tray column shows an advantage resulting from the use of a Turbogrid tray design in which maximum tolerance toward fouling was preferred over high efficiency. The separation achieved in the grid-tray installation is poorer at low rates, but the longer cycle between clean outs and the better separation at high throughputs more than offset this.

Turbogrid application No. 8 is a 2½-ft. diam. column scrubbing SO_2

Installation	Water Feed bbl./day	Stripping Steam lb./hr.	H₂S Concentration (p.p.m.) Inlet Water	H₂S Concentration (p.p.m.) Exit Water
Turbogrids	3,170	13,650	4,000	4
Bubble-cap trays	~2,800	10,000	~3,200	5-10

Table 4.—Comparison Turbogrid and Bubble-Cap Column Operation

Application No. 12

	Turbogrid Plant			Bubble-Cap Column Plant		
	Alcohol Column	No. 1 Ketone Column	No. 2 Ketone Column	Alcohol Column	No. 1 Ketone Column	No. 2 Ketone Column
Number of trays	15	20	20	10	20	25
Tray spacing, in.	18	24 & 21	18			
Feed rate gal./min./(sq. ft.)	5.80	3.22	5.09	4.24	1.61	2.62
Reflux/feed	0.28	1.2	1.37	0.20	0.57	1.40
Max. internal flows:						
vapor, lb./(hr.)(sq. ft.)	2700	3000	2900	1700	1100	1500
liquid, lb./(hr.)(sq. ft.)	700	2300	3000	370	550	1500
Tops, % light component	97.5	99.7	97.0	97.1	99.7	
% heavy component	2.5	0.3	3.0	2.9	0.3	1.8
Botts., % heavy component	87	1	99.5	89.6	1	99.5
% light component	13		0.5	10.4		0.5
% of calculated capacity	75	84	83			2

[1] Comparable samples not available.

[2] Plant column operation close to capacity.

Turbogrid trays (carbon steel bars) gave no evidence of corrosion after six months in this service.

The tenth application of Turbogrid trays is in the manufacture of a poly-hydric alcohol where an intermediate compound is stripped from an aqueous phase with steam. Residence time is a factor inasmuch as chemical reaction also occurs within the column. Twenty-four grid trays at 18-in. tray spacing replaced four 10-ft. sections of Raschig-ring packing in a 3½-ft. diam. column. The reason for the replacement was a desired increase in column through-put from 75 gal./min. to 180 gal./min. The grid-tray installation provides for these rates, not attainable with the packed column, and in addition pro-vides considerable tolerance to fouling. In plant operation the column has per-formed satisfactorily at 180 gal./min. feed rate and a stripping steam rate of 8,400 lb./hr. The recovery of the in-termediate has been 97% with less than 0.1% wt. loss in the bottoms; this re-covery duplicates that obtained with the original packed section.

Column No. 11 is used in the pre-fractionation of a crude chlorinated hydrocarbon. Carbonaceous material in the vapor feed required that the orig-inal bubble-cap installation be cleaned about once a month, with all the trays requiring cleaning. The Turbogrid in-stallation, a tray-for-tray replacement of twenty-four bubble-cap trays in a 4½-ft. diam. column (16 rectifying trays at 24-in. spacing and eight strip-ping trays at 27-in. spacing) has had an on-stream time of more than three months. In addition, clean-out time has been significantly reduced inas-much as the rectifying trays no longer

exhibit plugging tendencies and only the stripping trays require periodic cleaning. No difference in product qual-ity has been observed relative to the bubble-cap operation and the recovery of the chlorinated hydrocarbon in the bottoms has been maintained at about 100%. A 30% increase in capacity has been achieved with the Turbogrid in-stallation.

The last Turbogrid service discussed in this group, No. 12, actually uses three separate grid-tray columns. Table 4 summarizes the design essentials and performance for these columns and gives comparative performance results for bubble-cap columns in the same services in a parallel plant. Data show that comparable separation in these services can be attained with grid trays relative to bubble-cap trays at signifi-cantly higher feed rates and column flows, although involving higher reflux ratios in two cases.

Recent Turbogrid Installations

Turbogrid columns are being installed in essentially all of the plant expansions which the Shell companies have underway or have recently completed. Among these major units are: all columns (12) equipped with grid trays in the recently completed 16,000 bbl./day Platformer unit at Houston refinery; a new gas absorption plant (rectified absorber, de-propanizer, debutanizer); ammonia plant, gas purification; and essentially all columns in the major expansion of Norco refinery. In addition to these units, many other individual columns add up to a total of about ninety towers installed or under construction. In a subsequent publication it is planned to present informa-tion and performance data for various columns in the plants recently completed.

Two general types of Turbogrid construction referred to in a previous section are bar-type construction and the stamped-slot type. The bar-type construction was developed first, but has been superseded by the stamped-section type of tray for most designs. However, where a nonrectangular bar cross-section is to be used, the bar-type construction is still re-quired. For fabrication of Turbogrid trays from special materials, such as Karbate, that cannot be subjected to a stamping process, the slots can be milled in a flat plate of the material.

The bar type of Turbogrid construction is illustrated in Figure 1 referred to previously. It shows the general "backbone" of the tray which is fabricated initially as one piece. In-stalled, the peripheral support structure rests on the ring angle attached to the column shell and is bolted or welded to it. Shown also are the Turbogrid bars welded to the tray support structure prior to installation. The tray usually is sectioned before installation, in order to pass through manholes, and the sections then assembled on the ring angles within the shell. A tray section can serve as a manway, or a smaller part of one of the larger sections can be used for this purpose. For the tray design shown in Figure 1, nineteen trays of 5-ft. diam. required 54 man-hours of labor per tray for fabrication and installation. The division of labor in the preparation and installation of the trays was:

	%
Fabrication and installation of ring angles	42
Fabrication of Turbogrid trays	45
Installation of Turbogrid trays	13

The fabrication includes preparation of jigs used in manufacture of the nineteen grid trays. These trays replaced fourteen bubble-cap trays and the cost of the Turbogrid trays was about half that or replacement of bubble-cap trays; in addition, a considerable reduction in down-time was realized.

The bar-type Turbogrid tray has been installed and used successfully in columns up to 10½ ft. in diam. and has the advantage that it can be fabri-cated on relatively short notice with commonly available materials and workmen. However, the second gen-eral type of Turbogrid tray using the stamped slotted construction is a cheaper method on a large-scale basis and is recommended for most purposes. This type of tray contains standard perforated sections, approximately square, containing a variable number of slots, in a number of different slot widths, to meet the tray design specifi-cations. These standard sections are bolted to a tray support structure to form the over-all grid pattern. To fill out the tray near the periphery, sketch plates roughly triangular or trapezoidal in shape are used. With this type of tray one of the standard sections can

Table 5.—Comparative Cost Data—Turbogrid Trays and Bubble-Cap Trays

Service	Column Pressure lb./sq. in. abs.	Turbogrids Diam. ft.	Turbogrids Height ft.	Turbogrids Number[1] of Trays	Bubble Caps Diam. ft.	Bubble Caps Height ft.	Bubble Caps No. of Trays	$ Shop Cost (not Erected) Turbogrids Total	Turbogrids Trays	Bubble Caps Total	Bubble Caps Trays	$ Savings
Fractionator	50	7.5	91	50 + 1	8.5	102	40	22,250	11,250	40,400	25,000	18,150
Fractionator	20	8.5	127	80 + 1	10.5	120	65	49,400	28,000	84,500	61,400	35,100
Extractive Distillation	20	6.5	122	84 + 4	7.5	119	65	32,200	16,800	48,700	32,200	16,500
Solvent Stripper	15	4.0	73	40 + 2	5.5	67	30	11,200	4,000	16,600	8,250	5,400
LGO Stripper	23	9.0	42	19	10.5	42	14	19,000	11,500	27,000	13,750	8,000
Crude Fractionator	30	7.5	103	48 + 2	8.5	107	32	29,750	15,000	38,000	20,000	8,250
Vacuum Tower	1	16.5	37	7 + 3	19.0	34	7	52,500	14,500	63,000	21,000	10,500
S. R. Debutanizer	155	7.5	102	74	9.0	112	50	50,000	27,500	75,000	40,000	25,000
Depropanizer	340	3.5	82	50	4.5	82	38	15,000	3,400	22,000	7,700	7,000
Depropanizer-Debutanizer	225	3.0	67	42 + 1	3.5	72	30	10,500	2,800	13,700	4,200	3,200
Deisobutanizer	145	5.5	109	69 + 1	6.5	108.5	50	29,000	12,000	40,000	19,000	11,000
Depropanizer	415	4.0	63.5	41 + 1	5.0	71	30	18,000	4,500	27,000	7,000	9,000
Deethanizer	420	5.0	75.5	40 + 1	7.0	72	30	27,000	6,000	44,000	13,000	17,000

[1] Second number is number of distributor trays.

serve as a tray manway, accessible from above or below. Figures 5 and 6 show photographs of two standard stamped sections to meet two different sets of tray layout specifications. Figure 6 shows the stiffening channels on the bottom of the section required for these sections. The standard stamped sections are fabricated from thinner gauge metal sheet than the bar-type trays and can consequently be made from alloy steels at about the same cost as carbon steel bar trays. Thus they provide a more corrosion-resistant tray if such is required, at no extra cost.

The tray support structure for the stamped Turbogrid tray has been standardized for column diameters from 3 to 12 ft. in increments of 6 in. Thus the design calculations are limited to determination of the requisite open area and column diameter, which can be easily obtained in a combination of the standard section and standard support structure.

In the assessment of Turbogrid-tray installations over the past three years, detailed performance and cost comparisons relative to bubble-cap tray columns, to meet the same services, have been obtained. Table 5 summarizes relative column sizes and tray and total costs on a noninstalled basis for grid trays and bubble-cap trays for representative cases. These data afford a basis for estimating the savings that can be realized by the use of Turbogrid trays instead of bubble-cap trays in

either new or replacement service. The same standards of design and construction were used throughout for bubble-cap and Turbogrid columns. Figure 7 shows the saving for new installations, as dollars per square foot of required grid-tray area as a function of grid-tray column height H, number of trays N, and the system pressure P. The data indicate that savings range from $7/sq.ft. of grid-tray area at low pressures to more than $20 at high pressures (the factor H/N ranges in value ordinarily from 1.5 to 2.5).

Potential savings, resulting from replacement of bubble-cap trays with Turbogrid trays in an existing tower, vary according to the column service but generally are substantially greater
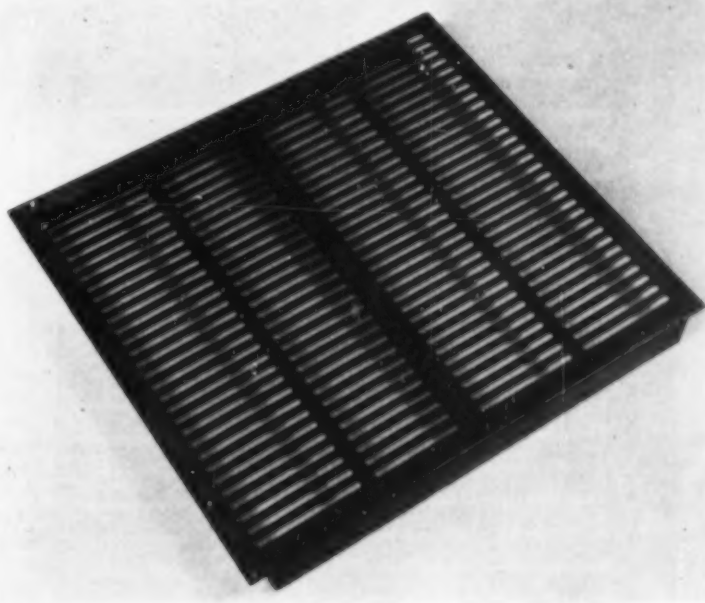
Figure 5. Top-angle view.
Construction of Turbogrid trays standard stamped sections.

than for new installations.

Data shown in Table 5 and Figure 7 indicate that substantial savings in fabrication cost can be had by the use of Turbogrid trays in virtually all cases. Savings in reduction in fouling and maintenance time are factors to which exact value cannot readily be assigned; they are, however, important and represent additional savings to those shown in Figure 7. In some cases the low-pressure-drop feature of the trays leads to smaller cost for auxiliaries such as gas compressors or vacuum ejectors.

SPECIALIZED APPLICATIONS OF TURBOGRID TRAYS

In addition to the use of Turbogrid trays in essentially all types of general fractionation service, their application

in a number of specialized uses has been considered. These applications have not been as fully explored as to the ultimate potentialities of grid trays as has been the field of fractionation; however, an adequate experimental basis exists for a preliminary evaluation of grid trays in these services. A consideration of these applications has been prompted by the success of grid trays in the field of distillation equipment and the lack of adequate equipment to meet the requirements of the new services.

DEENTRAINMENT

The use of Turbogrid trays in deentrainment service has been investigated for vacuum flasher

and steam boiler applications. In both of these cases carry-over of liquid entrainment will result in a consequent carry-over of undesirable materials—in the case of vacuum flashing, metallic impurities that tend to de-activate catalyst in subsequent cracking operations and in the case of steam boilers, of silica that precipitates on turbine blades. Removal of the carry-over of these materials would result in substantial savings in both of these applications. For use in vacuum flashers, grid trays with reflux offer low pressure drop per tray (1 to 3 mm.Hg), no dead zones for the accumulation of coke, efficient deentrainment of pitch, and sufficient fractionation for the removal of volatile metal-organic complexes, which are now known to vaporize at flasher furnace temperatures.

Experimental tests under simulated vacuum-

flasher conditions show that three grid trays remove 70 to 90 % of a liquid mist entrained in a vapor stream, the mean drop size of the mist being as low as 6μ and the concentration of mist in the inlet vapor being 0.1 to 0.3% w. Low reflux rates (0.06 to 0.30 gal/(min.)/(sq. ft. tower cross-section) were used in these tests. Experimental results have been applied to the design of deentrainment sections for four vacuum flashers in Shell refineries. For one of these installations, in a 20,500 bbl./day flasher, it is estimated that the reduction in metal contaminants (entrainment plus volatiles) effected by tray installation will reduce the cost of catalyst make-up, to maintain activity in the catalytic cracking unit, by about $200,000 per year.

Installations of Turbogrid trays and of sieve trays without downcomers have been tested in prototype and refinery steam boilers. A typical installation (5 trays at 3-in. spacing) gave deentrainment rates of 55% based on silica removal, with reflux at optimum rates. This applications study is continuing.

HEAT-TRANSFER SECTIONS

Turbogrid trays can be used in heat-transfer sections in two different ways. In the first method, a section of trays can be used to condense vapors and provide reflux, or to quench vapors to a desired temperature by a suitable, vaporizable reflux. Grid trays for this service have been installed in a reflux section in a 10-ft. diam. tower and are giving satisfactory operation.

The second method uses heat transfer to the vapor-liquid mixture on the grid tray from material condensing or vaporizing within the bars constituting the tray. The grid design for this type of installation would be fabricated from hollow round tubes. One of the obvious applications of this design is the fractionation of heat-sensitive materials, such as fatty acids, under vacuum conditions. The process requirements for low pressure drop, low liquid holdup, good tray efficiency, and high tray-side heat-transfer coefficient can be met by the grid-tray design. Heating medium, such as Dowtherm vapor, passes through each tray, thereby avoiding the conditions of long residence time and local overheating which occur if all the heat is put into the reboiler.

APPLICATIONS IN FOULING SERVICE

In addition to some installations (cited previously), made to minimize fouling encountered in general fractionation service, Turbogrid trays have been installed in residue strippers and in slurry sections in catalytic-cracking fractionators. Wide slots are used in trays for these services and, in addition, round bars or other special shapes may be used to prevent the accumulation of solids.

Literature Cited

1. Shell Development Co., *Petroleum Refiner*, **31**, No. 11, 105 (1952).

Presented at A.I.Ch.E. St. Louis meeting.

Fig. 6. Underside of section showing stiffening parts. Construction of Turbogrid trays standard stamped sections.

H = Turbogrid column height, seam to seam, ft
N = Number of Turbogrid trays required
P = Column pressure, psig

Fig. 7. Turbogrid cost data. Savings relative to bubble-cap trays—new installations.

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A tower packing for diffusional operations was developed, the design based on a principle of interstitial holdup rather than of wetted surface. When the performance of the packing was evaluated in an ammonia-air-water system, the transfer efficiencies obtained exceeded those of equal size Raschig rings and the Berl saddles by 35 to 125% as a function of flow rate. At elevated liquor flows the H.T.U. for this packing was found to be independent of liquid rate. The pressure drop obtained was independent of liquid rate and was in the range of pressure loss obtained with commercial packings. Nonwetting materials may be used (polyethylene was used for evaluation) in the construction of the packing, thus making available low-weight corrosion-resistant materials for packing construction. The use of a nonwetting wall liner was found to increase the transfer of Raschig rings and the new rosette by 25 to 50%.

The Rosette

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A New Packing for Diffusional Operations Based on High Interstitial Holdup

The design of column-packing materials for mass-transfer operations has been based traditionally on two major considerations: (1) large surface area for phase contact and (2) large free volume to minimize pressure drop.

Although th· factor of holdup has been investigated by Rose, Welshans, and Long (7) and Colburn and Stearns (2) and has been found (2) under various conditions to be beneficial to separation, this phenomenon has apparently not been investigated with respect to packing design.

Holdup, as a function of the packing itself rather than of flow conditions, occurs as a result of two factors: (1) design of the packing leading to interstitial holdup at points of contact between the various units of the packing and contact points of the different surfaces within the unit packing structure (for instance, wire contacts in the Stedman and McMahon packings), and (2) the adhesion of a liquid surface to the packing material.

The contribution of the inherent holdup of the packing to effective mass transfer may have been neglected in the evaluation of packing performance. For example, of the two industrially accepted packings, the Raschig ring and the Berl saddle, the saddle has in most cases evinced superior mass-transfer performance. This effectiveness of performance has generally been attributed to a larger surface area per unit volume, about 40% greater than that of the ring;

yet under dumped conditions the number of contact points between packing units per unit volume of the saddles is approximately twice that of the rings.

A possible effect of interstitial holdup was observed by the author in commercial and laboratory tower evaluation. It was found that in many packings the H.T.U. increased with $G^{0.2}$, as indicated by theory, up to 60 to 70% of flooding. Beyond this point, transfer efficiency increased and the H.T.U. decreased. Elgin and Jesser (3) reported that in this approximate range of throughput a change in column-flow characteristics due to an increase in interstitial holdup was observed. Thus, the increase in efficiency may be attributed to a longer holdup time of the liquid phase due to interstitial agglomeration and the accompanying phenomenon of more tortuous gas path initiated at this throughput rather than to increased wetting, as suggested by Leva (5).

Furthermore, the flooding of columns prior to operation is accepted as good operation practice. Justification of this procedure is normally made on the basis of prewetting the packing. It is just as feasible to relate the increase in efficiency to the creation of a false interstitial holdup which would normally occur at high throughput.

It was believed that a packing designed primarily to cause high inter-

stitial holdup would result in high efficiency of transfer for two reasons.

1. Increased interstitial holdup would cause the liquid to remain in the column for a longer period of time than occurs in conventional packing for the same throughput. Thus contact time for material transfer would increase.

2. Interstitial buildup of liquid in the column would restrict the paths of flow available to the gas phase; thus,

   a. higher local velocities would result, increasing the transfer rate,

   b. a more tortuous and therefore longer path for the gas phase would result. As a result, the effective column length for mass transfer would increase, resulting in lower H.T.U.'s since the H.T.U. is nominally measured by the vertical height of the packing.

The design of a packing was undertaken to evaluate this hypothesis. Polyethylene was chosen as the material of construction in order to minimize any wetting contribution to transfer. A packing that upon being dumped in a column that would afford a maximum of surface edge contacts and have high interlocking properties was desired, be-
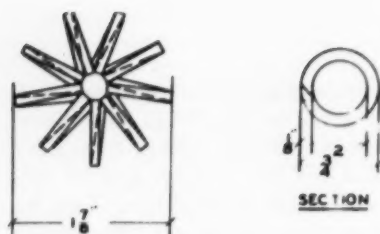
Fig. 1. Polyethylene rosette.

cause these characteristics afford high interstitial holdup. Helices have been known to present such characteristics in small-column operation but are inapplicable to large-column use. Multiple-turn helices compressed on being loaded in the column and operated, in effect, as Raschig rings.

The design of the high-holdup packing was based on a noncompressible multiple-turn helix. The shape may mathematically be referred to as a helical torus or, in lay language, a multiple helix in the form of a doughnut. It will be referred to in this paper as the *rosette* (Figure 1).

Two sizes were made for evaluation: the ¾ by 2 in. (nominal 1½-in. size) and the ½- by 1¼-in. (nominal ¾-in. size). The ¾- by 2-in. unit was made from a ¾-in. O.D. helix shaped in the form of a 2-in. O.D. torus. Nine helical turns were used per unit. The filaments were made of ⅛- by ¼-in. polyethylene strip.

The packing has the advantage of offering a large number of small surfaces upon which the liquid constantly impinges and divides and which require constant splitting of the gas stream. The physical characteristics of the packing compared with other 1½-in. nominal size packings are shown in Table 1.

Although, as indicated in Table 1, the rosette presented a larger surface area than is available in the other industrial packings, the effectiveness of this surface was purposely negated in this work by the choice of a nonwetting construction material, polyethylene.

The estimation of holdup points developed on dumping of the rosettes was based on the contributions to this phenomenon of both the valleys of the filaments of the rosette and the interlock-

ing contact points between the various units of the packing. It was found that under dumped conditions interlocking was in excess of 99% complete.

Volume occupied by unit rosette in complete interlocked position . . . . 1.10 cu.in.
Number of rosettes (¾ by 2)/cu.ft. of packed tower 1,560
Volume required for complete interlock of 1,560 units . . . . 1,716 cu.in.
or 0.993 cu.ft.

Therefore, interlocking was 99.3% complete.

Experimental Procedure

The column used in the evaluation work was a 6-in. I.D. packed column (Figure2A) having a packed height capacity of 5 ft. Liquid distribution was achieved by a multiple weir (Figure 2B).

The packing performance was evaluated by the absorption by city water of ammonia from low concentrations in air (less than 4% by weight). The ammonia was metered in the gaseous state and was blended with the air through 2 ft. of 2-in. pipe packed with saran gauze. Both ammonia and air flows were measured by Fischer and Porter Rotameters and water flow by a Bailey orifice meter.

Gas samples of 300 cu.cm. were obtained by mercury displacement, absorbed in 100 cu.cm. of a 2% (wt.) boric acid solution, and titrated with either 0.0300N or 0.0030N HCl depending on the concentration. The indicator consisted of five parts of 0.1% bromcresol green and 1 part of 0.1% methyl red in 1,000 parts of 95% ethyl alcohol.

Liquid samples were titrated with 0.5680N sulfuric acid, the indicator being 1.250 g. methyl red and 0.825 g. methylene blue in 1,000 ml. of 95% ethyl alcohol.

The selection of equilibrium concentrations was based on obtaining constant ammonia concentrations in the liquid and vapor phases over a one-half hour period taking samples every 10 min. It was noted that the time approach to equilibrium was far greater in the case of the rosettes than in the Raschig rings. This phenomenon was attributed to the greater holdup characteristics of the rosettes. The liquid analyses were made in each case in order to check the material balance. Coincident with the requirement for constancy of stream composition was the necessity for a material balance within 5%.

The method of filling the tower with packing varied from the traditional method in the case of the rosettes. Inasmuch as the density of the polyethylene was less than that of water, loading through a liquid-filled column was impossible. The packing was dropped into the open column

and compressed by tamping at 6-in. intervals to attain the degree of packing normally achieved by tapping the column when standard brittle packings are used.

Removal of the packing from the column was easily achieved by filling the column with water and agitating the packing. When the interlocking linkages were broken, the packing floated to the surface of the water and was easily removed.

Although the column diameter, 6 in., was small for 1½-in. nominal size packing when considered in the light of the acceptable practice of utilization of packing diameter to column diameter ratios of 1:7 to 1:10, it was felt that the filament characteristics of the material would overcome this handicap.

Calculation Method

The H.T.U. for each run was made by the calculation of the N_{OG} for the system by the Colburn equation (1):

$$N_{OG} = \int_{y_1}^{y_2} \frac{dy}{y - y^*} \frac{(1 - y)_f}{1 - y}$$

It was found that utilization of the lean-gas-mixture charts developed by Colburn for fresh liquid feed containing no absorbable material gave results in the range of accuracy obtained by graphical integration.

UNLINED COLUMNS

The initial comparison runs were made for ¾-in. glass Raschig rings and ¾- by 2-in. polyethylene rosettes in the 6-in. glass tower. The evaluations were made at air velocities of 400 lb./(hr.) (sq.ft.), and 625 lb./(hr.)(sq.ft.), and liquor flows ranging from 500 lb./(hr.) (sq.ft.) to 2,400 lb./(hr.)(sq.ft.)(Table 2 and Figures 3A and 3B). Although the nominal size of the rosette (1½ in.) was greater than normally used for a 6-in.-diam. column, performance superior to that of the Raschig ring was obtained. It was also noted that more reproducible data were obtained with the rosette, indicating more stable operation.

Table 4 shows a comparison of the relative efficiencies (1/H.T.U.) of the two packings tested, and Table 5, a comparison of the efficiencies of the 1½-in. rosettes with equivalent sizes of commercial packings reported by Fellinger (4).

Visual observance of the liquid-flow

Table 1.—Packing Characteristics

	1½-in. Raschig rings	1½-in. Berl saddles	¾- by 2-in. rosettes
Per cent free volume	60	70	83
Surface, sq.ft./cu.ft.	36	50	97
Weight, lb./cu.ft.	45	42	10
No., units/cu.ft.	380	650	1,560
No. of interstitial points/cu.ft., holdup points/cu.ft. (dumped)	760-1,520	1,300-2,600	12,500-25,000
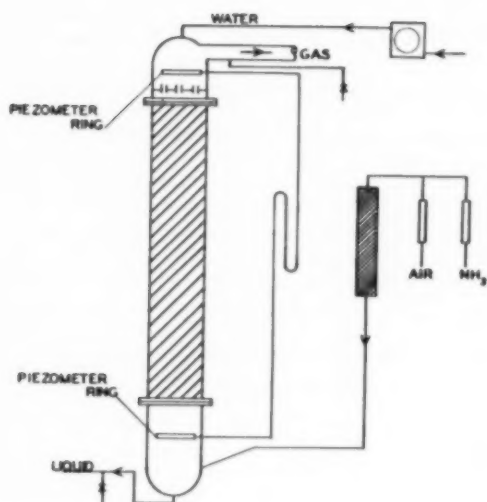
Fig. 2A. Column.

Fig. 2B. Distributor.

PLAN

SECTION
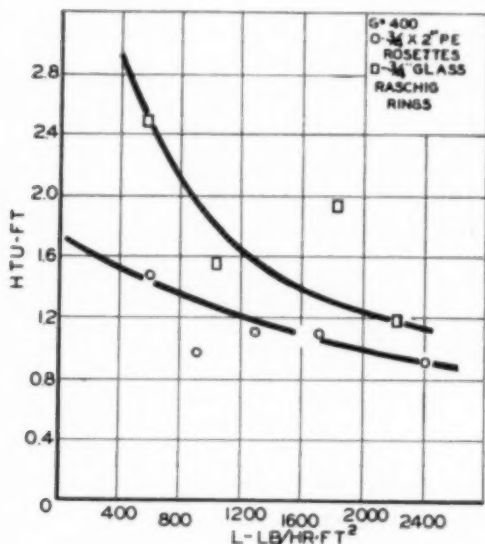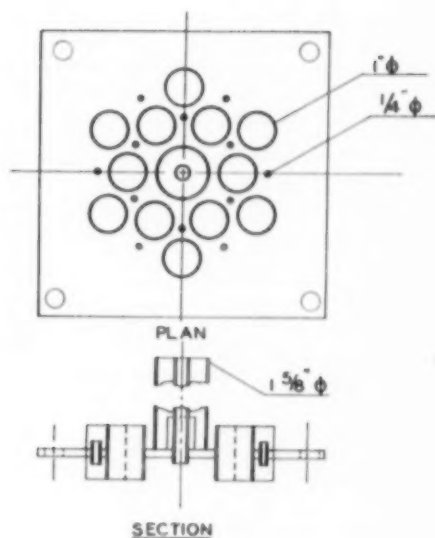
◄ Fig. 3A. Packing-efficiency comparison 6-in. glass column.

Fig. 3B. Packing-efficiency comparison 6-in. glass column. ►
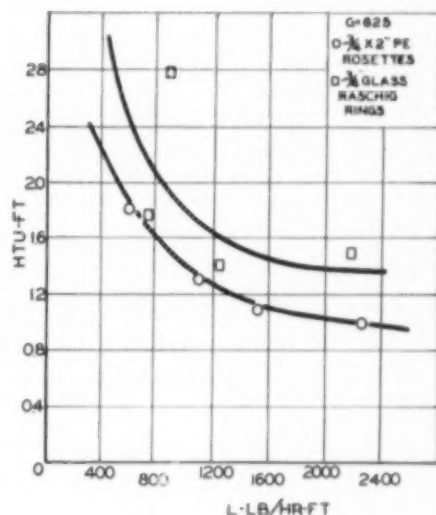
characteristics during operation with the rosettes indicated a large amount of liquid flow on the column walls increasing with column depth. This phenomenon was due to either or both of the following factors: (1) large nominal size of the packing creating high void space at the wall and (2) preferential wetting of the glass wall by the water. An attempt was made to overcome the second factor by providing the column with a nonwetting wall. The column was lined with polyethylene to an average thickness of 0.09 in. Because the liner was so thin, it was almost transparent. A light beam diametrically opposite the field of vision made the liquid flow at the wall visible. All liquid reaching the wall returned to the next unit of packing, touching the wall below the point of entrance of water to wall. Thus,

the amount of liquid flow on the wall was constant, independent of vertical position on the column.

An increase in packing efficiency was observed with both the glass Raschig rings and rosettes (Figures 4A and 4B). The results are compared in Table 6.

The increase in efficiency observed with the use of the rosettes rose from 28% at $L = 500$ to 54% at $L = 2,000$, a trend anticipated from the expected increase in wall action with increase in throughput. However the increase in efficiency obtained by wall liner with the Raschig rings remained in the range of 50% to $L = 1,500$ and then dropped to 33% at $L = 2,000$.

The performance of the rosette in the lined tower compared with that of the Raschig ring is indicated in Figure 5. Again superior performance is indicated

with attainment of transfer unit heights lower than 0.8 ft. at liquor velocities exceeding 1,400 lb./(hr.)(sq.ft.) and a gas velocity of 480 lb./(hr.)(sq.ft.); 1.57 ft./sec. It should be noted that the H.T.U. function is less affected by liquor velocity at $G = 480$ lb./(hr.)(sq.ft.) than is normally anticipated with the ring and saddle (Figures 4B and 5). This may be evidence of the anticipated type of liquor flow created by the packing design, that is, the droplet mechanism proceeding from one interstitial holdup point to another rather than film flow. Droplet flow mechanism should be independent of throughput, the only effect being merely a change in the mobility of the drops; whereas film flow characteristics should change with throughput, the change occurring in the thickness of the film and the turbulence

Table 2.

¾ in. Glass Raschig Rings—Unlined Tower
4.75-ft. packing

	Flow rate lb./(hr.)(sq. ft.)		Mole fraction NH_3		
Run no.	Air	Water	Inlet	Outlet	H.T.U.$_{oa}$
1	400	600	0.0616	0.0143	2.45
2	400	1,040	0.0620	0.00573	1.55
3	400	1,800	0.0624	0.00669	1.94
4	400	2,200	0.0624	0.000167	1.24
5	615	880	0.0642	0.0177	2.8
6	615	1,520	0.0673	0.0024	1.11
7	625	720	0.0640	0.0104	1.70
8	625	1,240	0.0732	0.00463	1.40
9	625	2,190	0.0645	0.00348	1.51

Polyethylene Rosettes ¾-by 2-in. Unlined Tower
3.4 = ft. packing

10	400	600	0.0653	0.0132	1.48
11	400	900	0.755	0.0053	0.97
12	400	1,300	0.0622	0.00486	1.10
13	400	1,700	0.0602	0.00342	1.08
14	400	2,410	0.0681	0.00210	0.93
15	625	620	0.0602	0.0182	1.8
16	625	760	0.0610	0.0157	1.8
17	625	1,100	0.0610	0.00835	1.25
18	625	1,520	0.0649	0.00552	1.10
19	625	2,280	0.0685	0.00352	1.00

3.8-ft. Polyethylene Rosettes ¾- by 2-in. Polyethylene-lined Tower
0.5-ft. ¾ in. Glass Raschig Ring Support Polyethylene-lined Tower

20	305	620	0.0679	0.00554	1.18
21	305	1,140	0.0679	0.00123	0.86
22	305	1,960	0.0675	0.00105	0.87
23	480	620	0.0604	0.00537	0.90
24	480	1,090	0.0604	0.00164	0.84
25	480	1,520	0.0679	0.00100	0.78
26	480	1,960	0.0604	0.000376	0.70
27	655	1,000	0.0601	0.00677	1.30
28	655	1,450	0.0601	0.00261	0.96
29	655	2,000	0.0587	0.00114	0.86
30	710	750	0.0580	0.0170	1.62
31	710	1,500	0.0580	0.00326	0.91
32	710	2,000	0.0585	0.00116	0.84
33	710	2,520	0.0585	0.00092	0.86

½- by 1¼-in. Polyethylene Rosettes Polyethylene-lined Tower
3.2-ft. Packing

34	480	500	0.0705	0.0157	1.52
35	480	860	0.0652	0.00269	0.81
36	480	860	0.0638	0.00264	0.81
37	480	1,560	0.0613	0.000894	0.69
38	480	1,560	0.0638	0.000555	0.62
39	480	2,040	0.0645	0.000547	0.62
40	585	1,100	0.0730	0.00188	0.67
41	585	1,560	0.0721	0.00126	0.67
42	710	730	0.0587	0.0167	1.95
43	710	970	0.0590	0.00513	1.05
44	710	1,560	0.0590	0.000693	0.60
45	710	2,040	0.0503	0.000503	0.60

Consideration was made of the contribution of 6 in. of ¾-in. glass Raschig rings under the rosette packing.

¾-in. Polyethylene Raschig Rings
4.67 ft. Packing—Polyethylene-lined Tower

46	400	520	0.0422	0.00883	2.45
47	400	1,140	0.0428	0.00171	1.25
48	400	1,560	0.0428	0.000685	1.0
49	495	560	0.0638	0.0133	2.17
50	495	1,100	0.0638	0.00387	1.32
51	495	1,560	0.0640	0.00180	1.13
52	495	2,040	0.0703	0.00081	1.03

¾-in. Glass Raschig Rings
4.5 ft. Packing—Polyethylene-lined Tower

53	480	370	0.0550	0.01045	1.82
54	480	620	0.0162	0.00616	1.54
55	480	1,100	0.0565	0.00069	0.88
56	480	1,570	0.0594	0.00103	1.0

engendered by increase in mass flow. At this gas velocity, normally encountered in industrial operations, similarity of the rosette performance to that of the bubble cap is observed with respect to constancy of efficiency of mass transfer. At higher gas throughput this constancy of efficiency is not observed until liquor velocities in excess of 1,400 lb./(hr.) (sq.ft.) are encountered (Figure 6).

Further tests were made with rosettes of ¾-in. nominal size to achieve a better comparison with the ¾-in. glass Raschig ring. A higher efficiency was obtained than with the use of the 1½-in. nominal size rosette (Figures 5 and 6). The H.T.U. obtained at $G = 480$ lb./(hr.) (sq.ft.) was less in all cases than 0.8 ft. achieving an H.T.U. of 0.6 ft. at $L = 2,000$ lb./(hr.)(sq.ft.) The variation of H.T.U. with liquor velocity was small, similar to that obtained with the larger rosette.

Initially polyethylene had been chosen as the material of construction for the rosette packing for two reasons: (1) to remove the contribution of wetting to mass transfer and thus ascertain the contribution of interstitial holdup alone and (2) to determine the utility of plastics as a material of construction in packing manufacture.

The relatively high efficiency obtained with the rosette in mass transfer required a determination of the effect of the polyethylene material itself on the process. An evaluation was made of the performance of ¾-in. polyethylene Raschig rings (Table 2) and comparison was made with the ¾-in. glass Raschig rings and the rosettes (Figure 5). The performance of the polyethylene Raschig ring was found to be inferior to that of the glass Raschig rings thus

Table 3.—Pressure-Drop Data

¾- by 2-in. Polyethylene Rosettes—3.83 Packing
6-in. I.D. column—Polyethylene Liner

Water rate lb./(hr.) (sq. ft.)	Gas rate lb./(hr.) (sq. ft.)	ΔP in. H_2O/ ft. packing
620	245	0.018
620	356	0.047
620	525	0.112
620	660	0.200
620	770	0.225
1,090	230	0.021
1,090	385	0.045
1,090	525	0.107
1,090	632	0.172
1,090	742	0.261
1,610	356	0.031
1,610	470	0.086
1,610	628	0.180
1,610	742	0.263
2,040	216	0.018
2,040	356	0.034
2,040	525	0.128
2,040	632	0.193
2,040	760	0.259

Table 4.—Test Comparison in 6-in. Unlined Glass Column

Table 4.—Test Comparison in 6-in. Unlined Glass Column

L = 1,000 lb./(hr.)(sq.ft.)

Basis—efficiency of ¾-in. glass Raschig ring = 100

G lb./(hr.)(sq.ft.)	¾-in. glass Raschig ring	¾- by 2-in. rosette
400	100	144
625	100	130

Table 5.—Comparison of Transfer Efficiency

G = 500 lb./(hr.)(sq.ft.) = 1.63 ft./sec.

Basis—efficiency of 1½-in. Raschig ring = 100

L lb./(hr.)/(sq.ft.)	1½-in. Raschig ring	1½-in. Berl saddle	¾- by 2-in. rosette
500	100	130	180
1,000	100	115	195
1,500	100	115	145
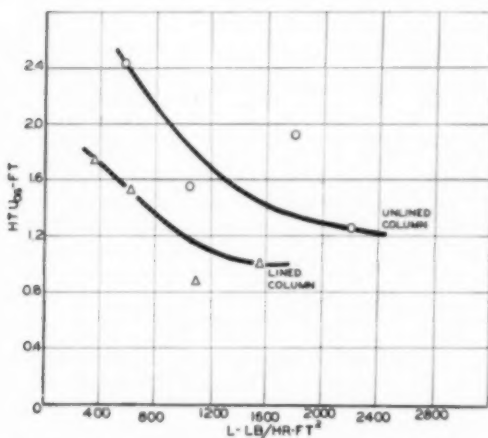
Fig 4A. Effect of wall liner on packing efficiency ¾ in. glass Raschig rings.
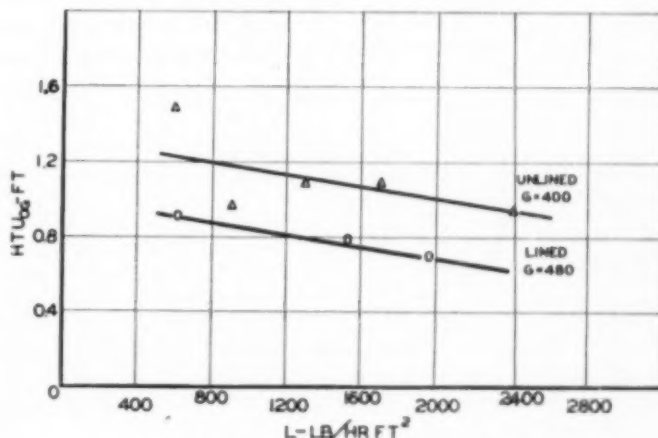
Fig. 4B. Effect of wall liner on packing efficiency ¾ × 2-in. rosettes.

Table 6.—Comparison of Packing Efficiencies in Lined and Unlined Towers

400/(hr.)(sq.ft.) G 480 lb./(hr.)(sq.ft.)—Basis—glass Raschig rings—unlined tower

L = 500   Efficiency = 100

L	Glass Raschig rings		Rosettes	
	Unlined tower	Lined tower	Unlined tower	Lined tower
500	100	154	205	272
1,000	135	209	215	294
1,500	172	250	231	325
2,000	192	255	250	367

indicating that under conditions of an equal number of interstitial holdup points, the wetting of the surface contributes to the transfer efficiency. This performance further indicates that it is the structural characteristics of the rosette resulting in increased interstitial holdup that cause the efficient performance of the packing.

Comparison of transfer efficiencies obtained with the rosettes was made with commercially accepted packings

and is indicated in Figures 7A and 7B and Table 7.

Pressure Drop

Pressure-drop characteristics were obtained for the ¾- by 2-in. polyethylene rosettes for the water flow range of 620 to 2,520 lb./(hr.)(sq.ft.) and air flow range of 230 to 780 lb./(hr.)(sq.ft.). The pressure drops encountered for the packing were found to be independent

of liquid flow rate in this range of flow. Thus it is apparent that the liquor flow characteristics are independent of liquor velocities. The theory of droplet flow falling between the packing interstices rather than of film flow would explain this phenomenon.

Comparison was made with pressure drops obtained by use of 1½-in. Raschig rings and 1½-in. Berl saddles as reported by Perry (6). The pressure drops obtained with the rosettes was greater than those reported for Berl saddles at L = 2,200 lb./(hr.)(sq.ft.) and less than that reported for 1½-in. Raschig rings at L = 2,100 lb./(hr.)(sq. ft.). (Table 3 and Figure 8)

The pressure drop obtained with the use of the ¾- by 2-in. rosettes for the flow range $620 < L < 2,520$ and for $230 < G < 780$ may be expressed algebraically as follows:

$$P \text{ (in. water/ft. packing)} = 0.003G^{2.16}$$

CONSTRUCTION OF ROSETTE

The shape of the rosette restricts its manufacture to metallic and plastic materials. The temperature range of operation limits the polyethylene material to absorption operations. To extend the utilization of this form in corrosion resistant plastics to distillation work, Kel-F and Teflon can be utilized as the material of construction. Extension of this shape to ceramics may be achieved by use of a shape approximating the characteristics of the new packing, the half rosette or spider created by passing a plane perpendicular to the axis of the torus through the center of the helix.

With the development of the noncompressible filamentous shape having high interlock characteristics, high mass-transfer efficiencies for packings can be obtained with nonwetting materials of
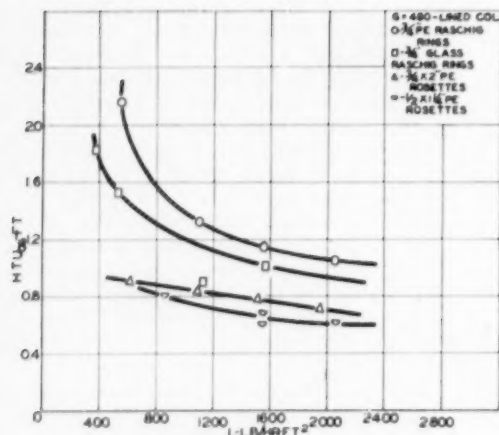
Fig. 5. Packing-performance comparison—
experimental evaluation.
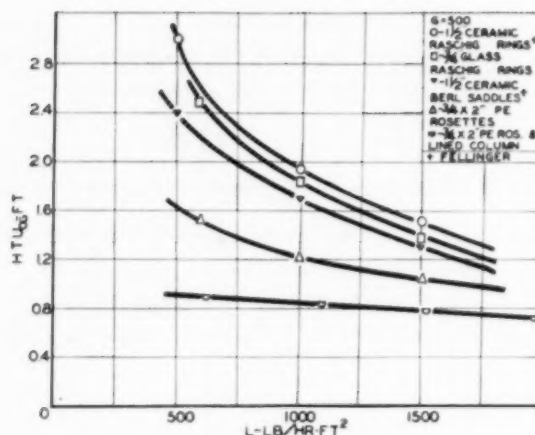
Fig. 7A. Packing-efficiency comparison.
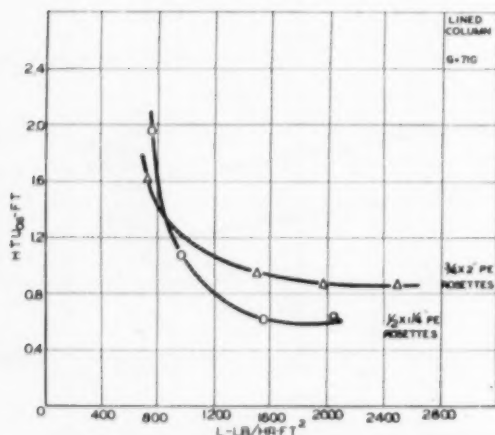
Fig. 6. Packing performance of rosette in lined column.
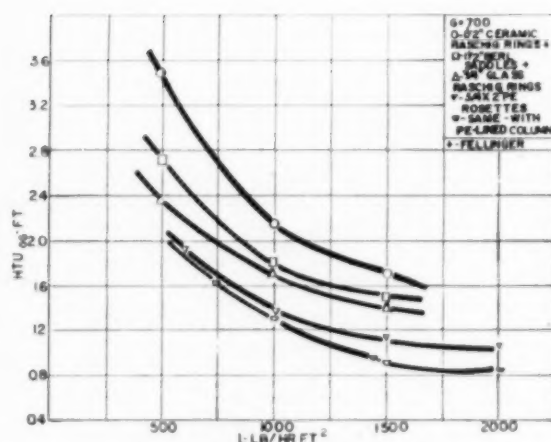
Fig. 7B. Packing-efficiency comparison.

Table 7.—Comparison of Transfer Efficiencies of Standard Packings and Polyethylene Rosettes

G = 550 lb./(hr.)(sq.ft.)   Gas = 1.8 ft./sec.

L = lb./(hr.)(sq.ft.) liquor

	500	1,000	1,500
1½-in. Raschig rings (ceramic)	100	100	100
1½-in. Berl saddles (ceramic)	127	112	116
¾-in. Glass Raschig rings	114	106	109
¾- by 2-in. Rosettes (unlined tower)	186	156	147
¾- by 2-in. Rosettes in lined tower	323	224	190
½- by 1¼-in. Rosettes in lined tower	...	250	220

G = 700 lb.(hr.)(sq.ft.)   Gas = 2.5 ft./sec.

L = lb./(hr.)(sq.ft.) liquor

	500	1,000	1,500
1½-in. Raschig rings (ceramic)	100	100	100
1½-in. Berl saddles (ceramic)	130	120	113
¾-in. Glass Raschig rings	146	129	121
¾- by 2-in. Rosettes (unlined tower)	160	155	151
¾- by 2-in. Rosettes in lined tower	170	169	185
½- by 1¼-in. Rosettes in lined tower	...	205	274

Data for 1½-in. Berl saddles and 1½-in. Raschig rings are from Fellinger.
¾-in. Glass Raschig rings tested in same tower as rosettes.
For any condition noted 1½-in. ceramic Raschig rings are rated at 100.
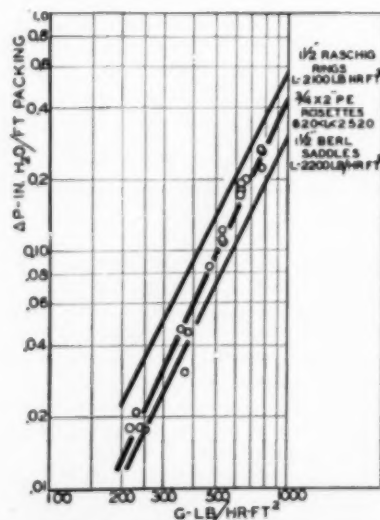
Fig. 8. Pressure-drop comparison.

construction. The efficiency of this type of packing is based on high interstitial holdup and on the increase in contact time and change in flow characteristics due to this design factor. Thus, a new class of materials, plastics, may be utilized for mass-transfer operations, advantage being taken of their properties of corrosion resistance, light weight, flexibility, and shock resistance.

Acknowledgment

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ABSTRACTS

Abstracts of papers published in "Applied Thermodynamics," Chemical Engineering Progress Symposium Series No. 7, Vol. 49 (1953). The volume may be purchased from Chemical Engineering Progress, 120 East 41 Street, New York 17, New York.*

Light-Hydrocarbon Vapor-Liquid Distribution Coefficients: Pressure-Temperature-Composition Charts and Pressure-Temperature Nomographs

C. L. DePriester
California Research Corporation

Experimental distribution coefficients were determined for thirty-three mixtures of light hydrocarbons at temperatures from −60° to 300° F. Variations up to 30% were found for individual components in a series of mixtures investigated at the same temperature and pressure.

Pressure-temperature-composition (P.T.C.) charts were developed for predicting fugacity relations of light hydrocarbons as functions of temperature, pressure, and molal average boiling point of phase. The distribution coefficient was obtained as the product of vapor- and liquid-phase fugacity functions.

A generalized correlation of distribution coefficients is presented, also, on pressure-temperature nomographs for temperatures from −100° to 400° F. and pressures from 14.7 to 800 lb./sq. in. abs.

Chem. Eng. Progress Symposium Series, **49**, No. 7, 1 (1953).

Fugacities In Gas Mixtures

Carroll O. Bennett
Purdue University

The P-V-T data of Hagenback and Comings have been used to calculate the activity coefficients of ethylene and nitrogen in various mixtures of these two sub-

stances at 50° C. and pressures from zero to 500 atm.

Joffe's method predicts the results best for this particular system, while the results using the Redlich and Kwong equation of state are not quite so satisfactory. The charts of Smith and Watson apparently should be used only to predict hydrocarbon vapor-liquid equilibria.

Chem. Eng. Progress Symposium Series, **49**, No. 7, 45 (1953).

Convergence Pressure in Hydrocarbon Vapor-Liquid Equilibria

Stuart T. Hadden
Socony-Vacuum Laboratories

In hydrocarbon systems at temperatures above the critical temperature of the lightest component where liquid and vapor phases can coexist, there is a pressure, specific for the temperature and composition, at which the equilibrium vaporization ratios, K's, of all components converge to unity. The theory of these convergence pressures is presented for ternary and more complex systems. It is shown that the convergence pressure is a function of the liquid-phase composition excluding the concentration of the lightest component.

Data are presented which permit the rapid estimation of convergence pressures for petroleum refinery operations. The concept of a quasiconvergence pressure is introduced for vapor-liquid equilibria at temperatures below the critical temperature of the lightest component and is shown to be valid for binary systems.

Chem. Eng. Progress Symposium Series, **49**, No. 7, 53 (1953).

An Equation of State for Carbon Monoxide Vapor-Liquid Equilibria for N₂-CO System

F. C. Schiller and L. N. Canjar
Carnegie Institute of Technology

Constants of the Benedict-Webb-Rubin equation for carbon monoxide have been determined and are reported for two different regions of the P-V-T plane. The equation that best fits the vapor-liquid dome was used to predict equilibrium-distribution ratios in carbon-monoxide-nitrogen systems. The results are compared with experimental data.

Calculated fugacity coefficients are also tabulated as a function of pressure, temperature, and composition for the carbon-monoxide-nitrogen system in the temperature range of 85° to 120° K.

Chem. Eng. Progress Symposium Series, **49**, No. 7, 67 (1953).

Hydrocarbon Partial Enthalpies

Lawrence N. Canjar and Wayne C. Edmister

I. Values for Methane, Ethene, Ethane, Propene, Propane, and n-Butane
L'Air Liquide Society

A method of obtaining partial enthalpies and entropies of the components of hydrocarbon mixtures from the ideal-gas-state values ($H°$ and $S°$) and the fugacities is presented. This method gives results that are consistent with the vapor-liquid equilibria ratios obtained from the same fugacities.

Values of $\overline{\Delta H}$ ($= \overline{H} - H°$) are computed for six light hydrocarbons in liquid and vapor mixtures from the f/x and the

$\bar{f}/Py$ values of Benedict, et al. The resulting partial-enthalpy differences are tabulated at pressures of 200, 400, and 600 lb./sq. in. abs. and at temperatures of $-100°$ to $400°$ F. for each of these six light hydrocarbons in vapor and liquid mixtures having molal-average boiling points of $-240°$ to $180°$ F.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 73 (1953).

II. Generalized Correlations

Carnegie Institute of Technology and California Research Corporation

The partial-enthalpy differences presented in Part I for six light hydrocarbons have been combined into generalized correlations giving $\overline{\Delta H}/T_c$ values as a function of T_r, P_r, and B_r (the ratio of average mixture boiling point to component boiling point) for both vapor and liquid mixtures. By means of these reduced parameters, the original values of $\overline{\Delta H}$, reported in the previous paper, have been smoothed and extended in range. With these generalized correlations, it is possible to estimate $\overline{\Delta H}$ values for other components not covered in the original study.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 85 (1953).

Thermodynamic Properties of Ternary Hydrocarbon Mixtures

J. M. Nelson and Dysart E. Holcomb
Purdue University

The enthalpies of three ternary hydrocarbon mixtures of different compositions of propane, n-butane, and n-pentane have been determined in both the liquid and vapor phases, including the two-phase region. The temperature range covered was from 240° to 400° F. and the pressure range from 100 to 800 lb./sq. in. abs. Various methods found in the literature have been tested.

Binary equilibrium data for the systems propane-n-butane and propane-n-pentane may be satisfactorily applied to the ternary mixtures studied. The type of flow calorimeter employed affords a rapid and accurate means of determining enthalpies of hydrocarbon mixtures at elevated temperatures and pressures in the single- and two-phase regions.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 93 (1953).

Heats of Mixing of Liquids

C. C. Tsao and J. M. Smith
Purdue University

Experimental data are presented for the heats of mixing at 25° C. and 1 atm. pressure for the binary and ternary systems composed of methanol, n-heptane, and toluene.

It was found that the power-series functions proposed by Guggenheim, Scatchard, Redlich and Kister, and others can be used satisfactorily to correlate binary heat of mixing data. These equations are applicable to the three different types of systems, endothermic, exothermic, and endoexothermic, provided the constants are evaluated by the least mean square method. Difficulties with approximate schemes which have been proposed for determining the constants are described.

A proposed method of predicting heats of mixing for ternary systems from binary data is shown to agree well with the available data.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 107 (1953).

Partial Molal Enthalpies of the Lighter Hydrocarbons in Solution with Other Hydrocarbons

A. Papadopoulos, R. L. Pigford, and Leo Friend
University of Delaware

The Benedict equation for the total enthalpy of hydrocarbon mixtures has been differentiated with respect to composition to yield an expression for the partial molal enthalpy of individual hydrocarbons in solution with other hydrocarbons.

Use of this expression has been made in calculating the partial molal enthalpies ($\overline{H}$) of methane, ethane, and propane in solution with other hydrocarbons both in the liquid and in the vapor phase for a temperature range of $-100°$ to $300°$ F. and a pressure range of 0 to 3,500 lb./sq. in. abs.

The results, correlated on the basis of the molal-average-boiling-point concept, are presented in the form of charts of $\overline{H}$ vs. pressure at constant temperature with lines of constant molal-average normal boiling point.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 119 (1953).

Critical Temperatures and Pressures of Hydrocarbons

G. V. Michael and George Thodos
Northwestern Technological Institute

The evaluation of critical temperatures and pressures for all types of hydrocarbons becomes possible only from a knowledge of the chemical structure of the particular compound. In this connection, a calculated parachor serves to produce the van der Waals constants a and b, which in turn define the critical temperature and pressure of the hydrocarbon through the expressions

$$T_c = \frac{8a}{27Rb} \qquad \text{and} \qquad P_c = \frac{a}{27b^2}$$

For the different hydrocarbon homologues, the van der Waals constants have been correlated with the parachor and are expressed empirically.

A comparison of calculated critical constants with available literature values used in this investigation produces an average absolute deviation of 1.8%. In this comparison are included literature values of questionable nature.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 131 (1953).

Volumetric Behavior of n-Pentane

Kun Li and L. N. Canjar
Carnegie Institute of Technology

The pressure-volume-temperature relationships of n-pentane in the liquid and vapor regions have been determined over a temperature range from 212° to 572° F. for pressures up to 3,200 lb./sq. in. Vapor pressures and saturated vapor and liquid volumes have also been measured at 302° and 347° F. No decomposition of n-pentane was observed at 572° F.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 147 (1953).

Thermodynamics Properties of n-Pentane

J. W. Brydon, N. Walen, and L. N. Canjar
Carnegie Institute of Technology

Thermodynamic properties of n-pentane are presented in the form of tables and a pressure-enthalpy plot. These properties are presented for both the liquid and the vapor phases over a range of 100° to 570° F. in temperature and 10 to 3000 lb./sq.in.abs. in pressure. The datum state is the pure component as an ideal gas at absolute zero temperature and 1 lb./sq.in.abs.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 151 (1953).

Thermodynamic Properties of Ethyl Ether

H. W. Schnaible and J. M. Smith
Purdue University

This paper presents a tabulation of volume, entropy, enthalpy and fugacity from 32° F. to the critical temperature 380.5° F. for the saturated region and from 32° to 600° F. and 0 to 1,000 lb./sq. in. abs. for the vapor region.

The properties were computed from available volume, vapor-pressure, specific-heat, and heat-of-vaporization information. It is estimated that the tabulated volumes, vapor pressures, and fugacities are accurate to within 1% but the entropy and enthalpy results may be subject to greater error.

Chem. Eng. Progress Symposium Series, **49,** No. 7, 159 (1953).

Reactions in Turbulent Free Jets —
The Turbulent Diffusion Flame

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Many technical applications involve reactions in free jets. A characteristic feature of these processes is the influence of the rate of mixing on the over-all conversion. A typical example is the diffusion flame. Here the rate of chemical reaction is comparatively high; consequently, the gross features of the flame—average concentration and temperature profiles and flame shape—are determined mainly by the rate of mixing of nozzle fluid and the entrained secondary fluid. In other cases the reaction time and the mixing time may be of the same order of magnitude.

To visualize the physical and chemical processes involved in the general case, one can consider a small volume (fixed in space) in a free jet in which a chemical reaction occurs. The reaction rate is a function of temperature and the concentration of reactants, products, and inerts. The temperature is determined by the diffusion of heat by molecular processes, transport of heat by the mean flow and the turbulent components, heat transfer by radiation, and heat generated by reaction. Similarly, each concentration is determined by molecular diffusion, transport by flow, and generation by reaction. The flow transport or convection depends on the distribution of mean and fluctuating velocities. To this physical situation corresponds a set of nonlinear partial differential equations: equations of motion, equation of continuity of each chemical species, and the equation of energy.

An exact analytical treatment of this problem is prohibitively difficult. An essential feature of any attack on this problem is the choice of simplifying assumptions. Care must be taken that these do not exclude any features just mentioned. Oversimplification leads to equations which are either at variance with experiment or contain "constants" which have to be adjusted to each new situation. For example, Burke and Schuman (2) attempt to calculate the height of laminar diffusion flames assuming a constant diffusivity (in spite of the extreme temperature changes occurring in a flame), and neglecting the effects of convection and

buoyancy. The resulting equation bears little resemblance to the empirical modifications of this equation by Wohl, Gazely, and Kapp (8) and Hottel and Hawthorne (6). Wohl et al. (8) also attempt a similar solution for the turbulent diffusion flame by assuming that the effective diffusivity in a turbulent flame may be expressed as

$$\epsilon = 0.0025\beta d(\overline{u_o} + \gamma)$$

where β and γ are constants. As a result of this arbitrary approach, both constants vary significantly with the per cent primary air and would presumably vary from one fuel gas to another, not to mention the effects of nozzle diameter and orientation with respect to gravity.

In a contribution by Hawthorne, Weddel and Hottel (4) the necessity of considering the equation of motion in the form of a momentum balance is recognized. However, they neglect all radial variations in concentration, velocity, and temperature. The resulting picture of the flame is an inverted cone burning only at the base. The mathematical development results in an expression for the diameter of the base which is assumed to be proportional to the height of the flame. The proportionality constant is determined by comparison with experiment. This approach is a step in the right direction. However, it cannot be used to obtain flame shapes, concentration and temperature profiles. Predictions concerning the effects of buoyancy are uncertain, since there appears to be no a priori reason to assume that the proportionality constant is unaffected by the buoyant forces.

This paper is restricted to turbulent jets. The mathematical technique used here is not intended as a contribution to the theory of turbulence. Rather should it be regarded as a summary and extrapolation of the body of experimental information available on free jets. In this sense, while shedding no light on the basic mechanism and structure of turbulence, it proves useful to the engineer.

Basic Equations

Under consideration is a differential volume in a free jet oriented with its axis (x) parallel to the gravitational field. The Fourier-Poisson equations for

heat transfer (neglecting radiation), and for mass transfer of the n chemical species are:

$$\frac{\partial}{\partial t}(c_p\rho\theta) = -div(-k\ grad\ \theta)$$
$$-div(\vec{V}c_p\rho\theta) + R_1\lambda \qquad (1)$$

and $\quad \dfrac{\partial}{\partial t}(\rho\chi_i) = -div(-D\ grad\ \rho\chi_i)$

$$-div(\vec{V}\rho\chi_i) - R_i;\ i = 1, 2, \ldots n \ (2)$$

The terms on the left in Equations (1) and (2) represent the total rate of accumulation; the second, third, and fourth terms represent the rate of accumulation due to molecular transport, flow, and chemical reaction, respectively.

Because of the assumed turbulence, the value of each dependent variable (at any point in the jet) fluctuates about a certain mean. For example,

$$\chi_i = \overline{\chi_i} + \chi_i'$$

and $\quad \overline{\chi_i} = \dfrac{1}{t}\displaystyle\int_o^t \chi_i dt \therefore \overline{\chi_i'} = 0$

where t is a time sufficiently large to encompass a large number of fluctuations. Clearly, in a turbulent field steady state never really exists. However, it is permissible to consider a quasi steady state for which the time derivatives of the mean values vanish, e.g., $\partial\chi_i/\partial t = 0$. Under these conditions, one obtains from Equations (1) and (2):

$$-div(\vec{V}\rho c_p\theta) + \overline{R_1}\lambda = 0 \qquad (3)$$

and $\quad div(\vec{V}\rho\chi_i) + \overline{R_i} = 0 \qquad (4)$

where the contributions due to molecular processes have been neglected. Similarly a balance over the axial component of the momentum together with the assumption of constant pressure yields,

$$-div(\vec{V}\rho u) \pm \overline{(\rho - \rho_B)g} = 0 \qquad (5)$$

where again the molecular transport is neglected. The positive sign in the second term applies when the axial velocity and the gravitational field have the same sense, whereas the negative sign applies when these vectors are of opposite sense.

To introduce the effect of turbulence on the various flux distributions, the following modifications of Reichardt's

(7) hypothesis by Baron and Alexander (1) are considered.

$$\overline{v\rho c_p \theta} = -\frac{C_\theta^2 x}{2}\frac{\partial(\overline{uc_p\rho\theta})}{\partial r} \tag{6}$$

$$\overline{v\rho\chi_i} = -\frac{C_z^2 x}{2}\frac{\partial(\overline{u\rho\chi_i})}{\partial r};$$
$$i = 1, 2, \ldots n \tag{7}$$

$$\overline{\rho v u} = -\frac{C_m^2 x}{2}\frac{\partial(\overline{\rho u^2})}{\partial r} \tag{8}$$

Equations (6), (7), and (8) represent mathematical assumptions justified only by previously successful applications to free-jet systems (1). In contrast to the theories of Prandtl and Taylor, these assumptions have no phenomenological basis. From an engineering point of view, however, their use in connection with free-jet systems is preferable to application of the phenomenological theories. The fundamental basis of these theories is being seriously questioned at present in scientific circles. Such theories are regarded as merely definitions of certain mixing lengths, and as such are reduced to purely mathematical statements of the type embodied in Equations (6), (7), and (8). Advantages of the latter with free-jet systems are:

1. Variations in the "spreading coefficients C" are negligible in contrast to significant and unpredictable variations in mixing lengths.

2. The problem of extension of phenomenological theories to fields of varying density is obviated.

3. Differential equations can be linearized frequently without the usually consequent restriction to small motions.

4. Solutions to many problems may be obtained in a simple and useful form.

5. Agreement between theory and experiment is good, in fact surprisingly so, in view of drastic assumptions involved.

Equations (3), (4), and (5) combined with Equations (6), (7), and (8), respectively, yield the following set of relations expressed in cylindrical coordinates:

$$\frac{\partial(\overline{c_p\rho\theta u})}{\partial x} = \frac{C_\theta^2 x}{2r}\frac{\partial}{\partial r}\left[r\frac{\partial(\overline{c_p\rho\theta u})}{\partial r}\right] + \overline{R_1\lambda} \tag{9}$$

$$\frac{\partial(\overline{\rho\chi_i u})}{\partial x} = \frac{C_z^2 x}{2r}\frac{\partial}{\partial r}\left[r\frac{\partial(\overline{\rho\chi_i u})}{\partial r}\right] + \overline{R_i}; i = 1, 2, \ldots n \tag{10}$$

and $$\frac{\partial(\overline{\rho u^2})}{\partial x} = \frac{C_m^2 x}{2r}\frac{\partial}{\partial r}\left[r\frac{\partial(\overline{\rho u^2})}{\partial r}\right] \pm \overline{(\rho - \rho_s)g} \tag{11}$$

Equations (9), (10), and (11) express the principles of conservation of energy, conservation of mass, and conservation of momentum, respectively. Two auxiliary relations are obtained from the equation of state and a rate equation,

$$\rho = \rho(T, \chi_i) \tag{12}$$

and $$R = R(T, \chi_i) \tag{13}$$

Effect of Turbulent Parameters

Dependent variables in Equations (9), (10), and (11) are the fluxes $\overline{c_p\rho\theta u}$, $\overline{\rho\chi_i u}$ and $\overline{\rho u^2}$. The effect of turbulence on these fluxes may be seen from the relation between the mean fluxes and the fluxes based on mean values, i.e. $\overline{c_p\rho\theta u}$, $\overline{\rho\chi_i u}$, and $\overline{\rho u^2}$. Writing each variable as the sum of its mean and fluctuating values, carrying out the indicated multiplications, and averaging, one obtains (1):

$$\overline{c_p\rho\theta u} = \phi_\theta(\overline{\rho c_p \theta u})$$
$$= (\overline{c_p\rho\theta u})\left(1 + \frac{\overline{T'u'}}{\overline{T}u} + \frac{\overline{\rho'u'}}{\overline{\rho}u} + \frac{\overline{T'\rho'}}{\overline{T}\rho}\right) \tag{14}$$

$$\overline{\rho\chi_i u} = \phi_{\chi_i}(\overline{\rho\chi_i u})$$
$$= (\overline{\rho\chi_i u})\left(1 + \frac{\overline{\chi_i'u'}}{\overline{\chi_i}u} + \frac{\overline{\rho'u'}}{\overline{\rho}u} + \frac{\overline{\chi_i'\rho'}}{\overline{\chi_i}\rho}\right) \tag{15}$$

and $$\overline{\rho u^2} = \phi_m(\overline{\rho u^2})$$
$$= (\overline{\rho u^2})\left(1 + 2\frac{\overline{\rho'u'}}{\overline{\rho}u} + \frac{\overline{u'^2}}{\overline{u}^2}\right) \tag{16}$$

where third-order moments have been neglected.

Over most of the reaction zone, temperature gradients are not much larger than in a nonisothermal jet issuing at the hot-spot temperature. For this case, Corrsin's (3) measurements indicate that the correction terms are not likely to exceed 20%. As a first approximation, these terms might be neglected entirely by setting $\phi_\theta \cong \phi_\chi \cong \phi_m \cong 1$. However, since this procedure introduces significant errors, especially in the neighborhood of the hot spots, only the following second approximation shall be used:

$$\frac{\phi_\theta}{\sqrt{\phi_m}} \cong \frac{\phi_{\chi_i}}{\sqrt{\phi_m}} \cong 1 \tag{17}$$

Consider now the effect of the turbulent fluctuations in temperature and

concentration on the buoyant force. In Equation (12) the density is expressed as a function of temperature and concentration. Alternatively, it may be considered to depend on temperature and molecular weight. Let $M = \overline{M} + M'$ and $T = \overline{T} + T'$. An expansion of $\rho(T, M)$ in a Taylor's series about the mean values of the temperature and the molecular weight yields:

$$\rho(T, M) = \rho(\overline{T}, \overline{M})$$
$$+ \left(T'\frac{\partial\rho}{\partial T} + M'\frac{\partial\rho}{\partial M}\right) + \frac{1}{2!}$$
$$\left(T'^2\frac{\partial^2\rho}{\partial T^2} + 2T'M'\frac{\partial^2\rho}{\partial T\partial M} + M'^2\frac{\partial^2\rho}{\partial M^2}\right) \tag{18}$$

where third-order terms are again neglected and each derivative is taken at the point $\overline{T}, \overline{M}$. Making use of the ideal gas law in obtaining the derivatives and averaging, one obtains:

$$\overline{\rho} = \rho(\overline{T}, \overline{M})\left(1 + \frac{\overline{\theta^2}}{\overline{T}^2}\frac{\overline{T'^2}}{\overline{\theta^2}}\right.$$
$$\left. - \frac{\overline{\Delta M}}{\overline{M}}\frac{\overline{\theta}}{\overline{T}}\frac{\overline{T'M'}}{\overline{\theta\Delta M}}\right) \tag{19}$$

The correction terms are again of the order of 20%. Now the buoyancy term in Equation (11) is itself frequently small compared to the other terms in that equation. Consequently, the approximation

$$\overline{(\rho - \rho_s)g} \cong (\overline{\rho} - \rho_s)g \tag{20}$$

seems permissible.

Similar considerations can be applied to the effect of fluctuations on the reaction rate. For simplicity, a reaction can be considered whose rate depends only on the temperature and the concentration of a single reactant. Then, proceeding as above, one obtains:

$$\overline{R(T, \chi)} = R(\overline{T}, \overline{\chi}) + \frac{1}{2}\left(\overline{T'^2}\frac{\partial^2 R}{\partial T^2} + 2\overline{T'\chi'}\frac{\partial^2 R}{\partial T\partial\chi} + \overline{\chi'^2}\frac{\partial^2 R}{\partial\chi^2}\right) \tag{21}$$

For example, if

$$R \propto exp\left(-\frac{\Delta E}{\underline{R}T}\right)\chi^2 \tag{22}$$

one obtains from Equations (21) and (22):

$$\overline{R(T, \chi)} = R(\overline{T}, \overline{\chi})\left[1 + \left\{\frac{\Delta E}{\underline{R}T} + \frac{1}{2}\left(\frac{\Delta E}{\underline{R}T}\right)^2\right\}\left(\frac{\overline{\theta}}{\overline{T}}\right)^2\frac{\overline{T'^2}}{\overline{\theta^2}} - \frac{\Delta E}{\underline{R}T}\frac{\overline{\chi'T'}}{\overline{\chi}\overline{T}} + \frac{\overline{\chi'^2}}{\overline{\chi}^2}\right] \tag{23}$$

The largest correction term in Equation (23) is

$$\frac{1}{2}\left(\frac{\Delta E}{\underline{R}T}\right)^2\left(\frac{\overline{\theta}}{\overline{T}}\right)^2\frac{\overline{T'^2}}{\overline{\theta^2}}. \text{ Now } \left(\frac{\Delta E}{\underline{R}T}\right)^2$$

is frequently of the order of 10^2 whereas (especially in the case of high-temperature reactions)

$$\left(\frac{\bar{\theta}}{T}\right)^2 \frac{\overline{T'^2}}{\theta^2}$$

may be of the order of 10^{-2} or 10^{-1}. Thus neglecting the correction terms could result in errors of several hundred per cent in estimating the mean reaction rate. Since the various correction terms cannot be evaluated with sufficient accuracy, the simultaneous solution of Equations (9), (10), and (11) is in general meaningless. Nevertheless, as shown hereinafter, solutions can be obtained in special cases, of which the turbulent diffusion flame is an important example.

Free Jets without Reaction—Buoyant Effects Negligible

In this simple case, Equations (9), (10), and (11) are independent of one another. Baron and Alexander (1) give the following solutions for fluxes originating entirely in the nozzle:

$$\phi_\theta \frac{(c_p\overline{\rho\theta u})}{(c_p\overline{\rho\theta u})_o} = \frac{d^2}{4C_\theta^2 x^2} \, exp\left(-\frac{r^2}{C_\theta^2 x^2}\right) \tag{24}$$

$$\phi_{\chi_i} \frac{(\overline{\rho\chi_i u})}{(\overline{\rho\chi_i u})_o} = \frac{d^2}{4C_\chi^2 x^2} \, exp\left(-\frac{r^2}{C_\chi^2 x^2}\right) \tag{25}$$

and

$$\phi_m \frac{(\overline{\rho u^2})}{(\overline{\rho u^2})_o} = \frac{d^2}{4C_m^2 x^2} \, exp\left(-\frac{r^2}{C_m^2 x^2}\right) \tag{26}$$

Each equation contains a single constant which can be evaluated by comparison with experiment. Suggested values for the constants obtained from an analysis of Hinze's (5) data are: $C_m = 0.075$ and $C_\lambda = C_\theta = 0.0855$.

Free Jets without Reaction—Appreciable Buoyant Forces

In this case, Equations (9) and (10) again have the solutions (24) and (25), respectively. Nevertheless, buoyancy affects the distribution of $\overline{\chi_i}$ and $\overline{\theta}$ through its effect on $\bar{u}$. For calculation purposes, it is convenient to rewrite Equation (11) in the dimensionless form:

$$\frac{\partial m}{\partial (x/d)}$$
$$= \frac{C_m^2(x/d)}{2(r/d)} \frac{\partial}{\partial (r/d)} \left[(r/d) \frac{\partial m}{\partial (r/d)} \right]$$
$$\pm Fr\left(1 - \frac{\rho_s}{\rho_o}\right) \frac{\bar{\rho} - \rho_s}{\rho_o - \rho_s} \tag{27}$$

where $m = \phi_m \dfrac{(\overline{\rho u^2})}{(\overline{\rho u^2})_o}$ (28)

and $Fr = \dfrac{dg}{\overline{u^2_o}}$ (29)

Equation (27) may now be solved with the aid of Equations (24) and (25) for any value of the product of the Froude number and the group $(1 - \rho_s/\rho_o)$ by the method of finite differences. The procedure is as follows: At any point in the jet m, $\bar{\theta}$, and $\overline{\chi_N}$ are known. The dimensionless density $\bar{\rho} - \rho_s / \rho_o - \rho_s$ is calculated and from Equation (27) the new value of m at a neighboring point is obtained. For this new point, from Equations (24) and (25), the values are calculated of $(\overline{\rho\chi_N u\phi_x}) = f_\chi$ and $(c_p\overline{\rho\theta u\phi_\theta}) = f_\theta$ and also from m is obtained the new value of $f_m = (\overline{\rho u^2}\phi_m)$. Then the new values of θ and $\overline{\chi_N}$ may be known with the aid of Equation (17) by simultaneous solution of the following set of equations:

$$\frac{f_\chi}{\sqrt{f_m}} = \overline{\chi_N}\sqrt{\bar{\rho}} \, \frac{\phi_\chi}{\sqrt{\phi_m}} \tag{30}$$

and

$$\frac{f_\theta}{\sqrt{f_m}} = c_p\bar{\theta} \sqrt{\bar{\rho}} \, \frac{\phi_\theta}{\sqrt{\phi_m}} \tag{31}$$

This procedure is repeated until the whole field is explored.

Turbulent Diffusion Flame—Negligible Buoyant Force

An exact solution of Equations (9), (10), and (11) for this case is impossible because the effects of temperature and concentrations of the various stable and unstable species on the reaction rate are not known. Furthermore, in the absence of reliable turbulence data, the quantitative effect of the fluctuations on $\bar{R}$ cannot be evaluated. Fortunately, however, the problem can be solved with the aid of three essential simplifications. Following Burke and Schuman (2) and Hawthorne, Weddel and Hottel (4), the following assumptions are made:

1. The combustion reaction takes place instantaneously.
2. The flame envelope is the locus of all points characterized by the stoichiometric concentrations.
3. The temperature in the flame envelope is the adiabatic heat balance temperature corresponding to the stoichiometric mixture.

The concentration distribution in the flame is most conveniently described in terms of a derived quantity (4) "based on a conversion of the gas sample to its equivalent composition prior to any combustion and the identification of the fraction of the converted sample which came from the nozzle." The mole fraction of the "nozzle fluid" defined in the above sense will be denoted by y. It should be noted that "nozzle fluid" is

neither created nor destroyed, hence $\overline{R_N} \equiv 0$.

Now, the solutions of Equation (10) written for the nozzle fluid and Equation (11) are given by Equations (25) and (26). Dividing Equation (25) (written with subscript N) by the square root of Equation (26), eliminating ϕ_N and ϕ_m with the aid of Equation (17) and rearranging, the following is obtained:

$$\chi_N = \sqrt{\frac{\rho_o}{\bar{\rho}}} \, \frac{dC_m}{2C_\chi^2 x}$$
$$exp\left[-\left(\frac{r}{x}\right)^2 \left(\frac{1}{C_\chi^2} - \frac{1}{2C_m^2}\right)\right] \tag{32}$$

The relationship between χ_N, the mass fraction of nozzle fluid in the unconverted sample, and y, the mole fraction of nozzle fluid in the converted sample, is

$$\chi_N = y \frac{M_o}{M_u} a \tag{33}$$

where M_u denotes the molecular weight of the unconverted sample, and a is the ratio of the moles of converted sample and the moles of unconverted sample. Combining Equations (32) and (33) and using the ideal gas law, one obtains:

$$y = \sqrt{\frac{1}{a^2} \frac{T}{T_o} \frac{M}{M_o} \frac{C_m d}{2C_\chi^2 x}}$$
$$exp\left[-\left(\frac{r}{x}\right)^2 \left(\frac{1}{C_\chi^2} - \frac{1}{2C_m^2}\right)\right] \tag{34}$$

At the tip of the flame, $x = L_T$, $r = 0$, $y = y_T$, and $a = a_T$ (by assumption 2), $T = T_f$ (by assumption 3), and $M = M_T = a_T[y_T M_o + (1 - y_T) M_s]$. Substitution of these conditions and the numerical values of $C_m (= 0.075)$ and $C_\chi (= 0.0855)$ into Equation (34) yields a useful expression for the flame height,

$$\frac{L_T}{d} = \frac{5.2}{y_T} \sqrt{\frac{T_f}{a T_o} \left[y_T + (1 - y_T) \frac{M_s}{M_o} \right]} \tag{35}$$

an equation identical in form with that proposed by Hawthorne, Weddel and Hottel (4). Their empirical constant 5.3 agrees within experimental error with the constant 5.2 of Equation (35).

In the flame envelope the conditions are $r = r_T$, $y = y_T$, $T = T_f$, $M = M_T$, and $a = a_T$. The flame shape may be obtained by substituting these conditions as well as the numerical values of C_m and C_χ into Equation (34) and solving for r_T. With the aid of Equation (35), one obtains for the flame diameter,

$$D_T = 0.29x \sqrt{\ln \frac{L_T}{x}} \tag{36}$$

The maximum flame diameter occurring at $x = 0.61 L_T$ is

$$D_{T\,max} = 0.12 L_T \tag{37}$$

Figure 1 compares the theoretical curve as given by Equation (36) with a tracing from a photograph of a 100%

city gas flame shown by Wohl *et al.* (*8*). Except for the ragged edges caused by flickering, the agreement is satisfactory. The flickering of course has been eliminated from the theory in the averaging process leading to Equations (*3*), (*4*), and (*5*).

Fig. 1. Experimental and theoretical flame shapes. Full line represents Equation (36); dotted line represents tracing of photograph by Wohl et al. (8).

The concentration distribution is given by Equation (34). The temperature profile may be obtained by recognizing that any sample within the flame envelope consists of excess nozzle fluid originating at the nozzle temperature and combustion products originating at the adiabatic flame temperature corresponding to a stoichiometric mixture (this follows from assumptions 1, 2, and 3). Similar considerations apply to samples outside the flame envelope. It follows that, apart from radiation effects, the temperature at any point in the field is simply the adiabatic heat balance temperature corresponding to the concentration of nozzle fluid at that point.

Turbulent Diffusion Flame—Appreciable Buoyant Force

The effect of the buoyant forces on the turbulent diffusion flame may be evaluated by the method already described for the case of free jets without reaction. In upright flames buoyancy increases the rate of mixing, thereby decreasing the height and diameter of the flame.

Intermingling of Parallel Flames

The effect of parallel flames on one another can be obtained by methods similar to those used above upon recognizing that the basic differential Equations (3), (4), and (5) are linear when the generation terms vanish (*1*). Thus, it is possible to obtain solutions for a system of several sources by superimposing solutions for the individual sources. For instance, for a system of N flames originating in the same plane, the following equation should take the place of Equation (24)

$$\phi_\theta(c_p\overline{\rho\theta u}) = \sum_{j}^{N} \frac{(c_p\overline{\rho\theta u})_{\theta f}d_j^2}{4C_\theta^2 x^2}$$

$$exp\left(-\frac{r_j^2}{C_\theta^2 x^2}\right) \qquad (38)$$

with similar equations replacing Equations (25) and (26). Here r_j is measured from the axis of the j-th flame. The flame shape, temperatures, and concentrations may be evaluated exactly as in the case of single flames, though admittedly at the expense of considerably more work. Qualitatively, the effect of several flames on one another should be to increase flame height and flame volume. This effect is most easily visualized for intermingling flames. Here the surface-to-volume ratio is reduced resulting in poorer mixing and increased flame volume.

Conclusions

1. The usefulness of Reichardt's hypothesis as modified by Baron and Alexander has been demonstrated for free-jet systems with large temperature and density gradients.
2. Spreading coefficients are true constants of free-jet systems.
3. Equations derived for macroscopic flame characteristics, notably for the flame shape, are in good agreement with experiment.
4. As a direct consequence of the modified Reichardt hypothesis, the fundamental conservation equations are linearized. This allows treatment of intermingling parallel flames.
5. Buoyancy tends to decrease the height and volume of upright flames.
6. Because of turbulence, the time-mean rate of reactions with high activation energies may differ by an order of magnitude from the rate corresponding to the time-mean conditions.
7. Methods used are useful to engineers. They are not intended as tools for the investigation of the structure of turbulence or flames.

Notation

c_p = local specific heat
C = spreading coefficient
d = nozzle diameter
D = flame diameter
D = diffusivity
ΔE = activation energy
I = flux, flow per unit area per unit time
Fr = Froude number
g = acceleration of gravity
k = coefficient of thermal conductivity
L_T = length of turbulent flame
m = momentum flux ratio defined by Equation (28)
M = molecular weight
$\Delta M = M - M_S$
N = number of flames
r = radial coordinate

R = reaction rate per unit volume
$\underline{R}$ = gas constant
t = time
T = absolute temperature
u = axial component of velocity
v = radial component of velocity
$\vec{V}$ = velocity
x = axial coordinate
y = mole fraction of "nozzle fluid"

GREEK CHARACTERS

a = ratio of moles of converted sample and moles of unconverted sample
β = constant
γ = constant
ϵ = eddy diffusivity
θ = temperature based on temperature of secondary (entrained) fluid
λ = heat of reaction
ρ = density
ϕ = correction factor for turbulence
χ = mass fraction

SUBSCRIPTS

o = nozzle conditions
l = limiting reactant
f = adiabatic flame
i = i-th species
j = j-th flame
m = momentum transfer
N = nozzle fluid
S = secondary fluid
T = turbulent flame envelope
u = unconverted sample
θ = heat transfer
χ = mass transfer

SUPERSCRIPTS

⁻ and ′ denote time-mean and fluctuating components of any variable, e.g., $u = \bar{u} + u'$

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The Evaporation of Solids into Laminar Air Streams

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The experimental study of mass transfer into laminar streams has not received the same attention that has been directed to turbulent diffusional processes. Gilliland (4) made important measurements of the rate of evaporation of pure liquids into a viscous air medium in a vertical, wetted-wall column of circular cross section. His mass-transfer rates were considerably greater than those predicted by the theoretical equation of Graetz (5). It was suggested later by Boelter (2) that natural convection had supplemented the normal transfer process and so had increased the rates.

Linton and Sherwood (9) measured the rates of solution of slightly soluble solids into laminar water streams in circular pipes. Their results agreed with a modification of Graetz's equation which was developed [1] by Lévêque (7).

No data could be found concerning the mass transfer of solids into laminar air streams. For practical reasons, therefore, this study was attempted to acquire the necessary data in square ducts, and to test the experimental results with a theoretical equation discussed in a former article (3). There it had been proposed that

$$\phi = 1.45\psi^{3/5} \quad \text{for} \quad 1/\psi > 20.$$

where ϕ = final per cent saturation of solid in air.

$$\psi = \frac{LD}{\rho H^2 V},$$

a modified form of the Graetz number. and

L = over-all length of vaporizing pan, cm.
D = diffusivity of vapor into air, g. moles/(cm.)(sec.)
ρ = molar density of air stream, g. moles/cu.cm.
H = over-all width and height of duct, cm.
V = mean velocity of air, cm./sec.

This paper describes the method of attack used in the investigation and determines the validity of the suggested expression.

Experimental Equipment

The apparatus used in this work is shown in Figure 1. It will be observed that air was drawn through a vaporization chamber by a rotary vacuum pump. This arrangement prevented the entrance of oil mist from the pump into the chamber and gave the most consistent data. Air volumes ranging from 0.1 to 5 cu.ft./min. were measured by a bellows-type, dry gas meter which was checked at frequent intervals.

The air medium was preheated to a desired temperature by an electric heater consisting of a number of resistance elements mounted in the center of a coil of ⅜-in. copper tubing. The temperature of the air was measured by a copper-constantan thermocouple A and a Brown self-balancing potentiometer.

The vaporization chamber was made from square brass duct, 15 ft. in length and 2.77 in. inside width. Approximately 8 ft. of the inlet

and 6 ft. of the exit sections were used for calming zones. The duct was heated by a number of separate resistance windings and was insulated with flat layers of 1-in. block magnesia. Copper-constantan thermocouples B, D, E and F aided in the maintenance of required operating conditions.

The actual vaporizing section of the unit (Fig. 2) shows that a rectangular portion of the bottom wall was removed from the duct and the inside edges of the cut smoothed. Pans made of aluminum of dimensions 8¾ in. × 2⅝ in. × ⅛ in. were filled with the required solid and the surface was smoothed with a warm porcelain spatula. This vaporizer was placed on a steel plate, and a wooden cover and these pieces were held tightly in the proper position by wing nuts. Soft rubber gaskets placed between the cover and a steel flange sealed the pan from the atmosphere. Four steel pins attached to the sides of the steel plate contacted the bottom of the brass pipe and located the evaporating area of the pan at the same level as the bottom inside surface of the duct.

It will be noted that an electric heater was placed below the steel plate to govern solid temperature. A copper-constantan couple (not shown) was attached to the upper surface of the plate for temperature control. Variation in the temperature of the vaporizing unit was also prevented by the use of special heaters attached to the top and two sides of the chamber. During a run it was found possible to maintain all of the measured temperatures within 2° C. The rate of evaporation was measured by weighing the solid before and after each run. Since the solids were volatile, small corrections had to be made for losses that occurred during transfer and weighing. These corrections ranged from one to four per cent of the solid evaporated for each weighing.

Experiments were carried out in the following manner:

The pan containing the solid was covered with aluminum foil and placed in the vaporization chamber. The vacuum pump was started and the temperatures were adjusted to the desired values. When conditions were satisfactory the vacuum pump was stopped to prevent the cooling of the unit, and the sample pan was removed. The aluminum foil was stripped from the vaporizing surface and the pan was weighed and replaced as quickly as possible. The pump was restarted and small temperature adjustments were made. At the end of two to four hours the pan was again removed and finally weighed.

The solids used in this study were all obtained as Analar reagent chemicals from British Drug Houses in Toronto. They were used without further purification except in the case of camphene. This substance was repurified by distillation at reduced pressure and a midfraction tested.

Vapor-pressure data needed for experimental correlation were taken from the literature (1, 6, 10). The diffusivity of vapor into the air stream was calculated by the method of Gilliland (4).

Comment

Seven pure solids were vaporized into laminar air streams; the data are shown in Figures 3 to 5 and summarized in Tables 1 and 2. It will be observed that a log-log plot of ϕ vs. $1/\psi$ yielded a series of straight lines all of which had the predicted theoretical slope. Camphor and acetamide approached the theoretical line derived in a former study (3). All other substances evaporated at individually different rates greater than that prescribed by the theory.

It will be recalled that the theory supposed vapor diffused vertically upwards and was then moved forward by the air stream. No diffusion was assumed to take place in directions parallel to the plane of the pan. In the theoretical paper (3) in which the velocity distribution in a square pipe was determined, no account was taken of the fact that the air viscosity near the pan could be different from that in the main body of the stream.

The fact, however, that all the data may be plotted with the theoretical slope but with different intercepts, indicates that some other factor must be involved. It is unlikely that this factor is the effect of solute concentration on stream viscosity since this would decrease the rate of evaporation and produce low values of ϕ for the small values of $1/\psi$.

The divergence could be explained by errors in the values of the diffusion coefficients; these were calculated and not experimentally determined. Errors might occur in addition if the vapor
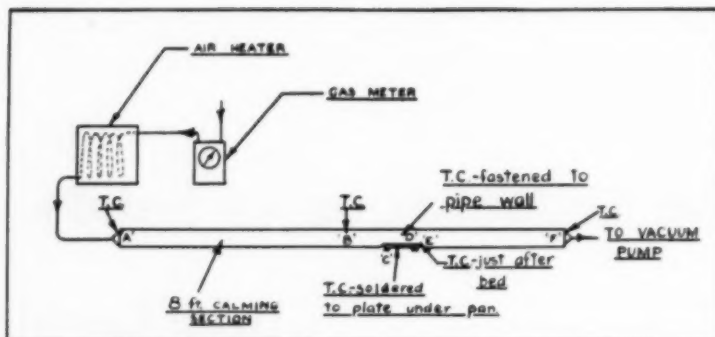
Fig. 1. Diagram of vaporization apparatus
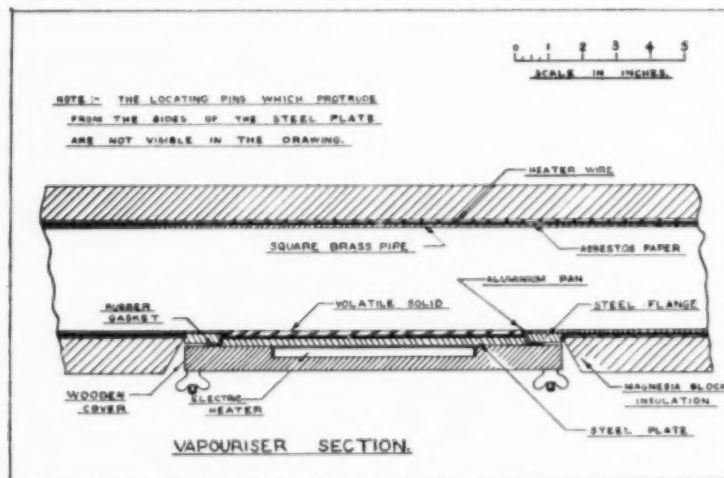
Fig. 2.
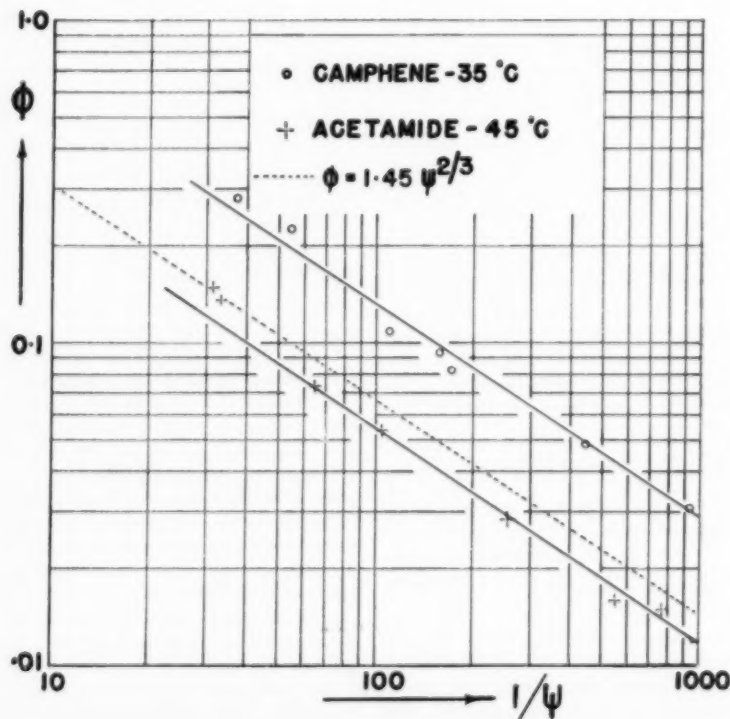
Fig. 3.

Table 1.—Rates of Evaporation of Naphthalene at Varied Temperatures

Run	cu.ft./min. Flow Rate Meter	Temp. Meter °C.	Pressure at Meter mm. Hg	Evap'n Rate g.moles/sec.	Pressure at sample mm. Hg	$\rho H^2 V$	ψ	$1/\psi$	ϕ	N_{Re}
				Temperature 35° C.						
N-3-1	0.509	23.1	754	2.26×10^{-7}	753	9.80×10^{-5}	6.06×10^{-3}	165	0.0725	215
N-3-4	0.157	22.7	751	1.51×10^{-7}	750	3.04×10^{-5}	1.97×10^{-2}	50.8	0.1586	66
N-3-7	2.739	23.3	744	3.38×10^{-7}	719	5.24×10^{-4}	1.142×10^{-3}	875	0.0197	1140
N-3-11	1.238	22.9	756	2.63×10^{-7}	751	2.38×10^{-4}	2.505×10^{-3}	398	0.0350	525
N-3-16	3.687	23.8	760	4.38×10^{-7}	708	7.20×10^{-4}	8.30×10^{-4}	1203	0.0182	1566
				Temperature 45° C.						
N-2-2	3.607	22.4	738	13.69×10^{-7}	688	6.86×10^{-3}	8.85×10^{-4}	1130	0.0248	1440
N-2-3	1.216	22.5	741	8.66×10^{-7}	736	2.32×10^{-3}	2.62×10^{-3}	382	0.0498	488
N-2-9	2.616	21.9	750	8.93×10^{-7}	728	5.06×10^{-3}	1.20×10^{-3}	834	0.0232	1060
N-2-10	0.605	21.8	749	5.94×10^{-7}	748	1.17×10^{-3}	5.19×10^{-3}	193	0.0686	246
N-2-14	0.093	24.4	744	3.88×10^{-7}	744	1.78×10^{-3}	3.41×10^{-2}	29.3	0.294	37
				Temperature 55° C.						
N-33	1.889	27.8	753	19.40×10^{-7}	741	3.60×10^{-3}	1.71×10^{-3}	585	0.0312	744
N-35	3.675	25.8	752	23.83×10^{-7}	700	7.04×10^{-3}	8.76×10^{-4}	1141	0.0185	1458
N-36	3.019	25.8	753	20.62×10^{-7}	719	5.75×10^{-3}	1.063×10^{-3}	940	0.0200	1198
N-37	0.937	28.0	753	15.41×10^{-7}	750	1.78×10^{-3}	3.45×10^{-3}	290	0.0506	370
N-43	0.369	27.5	756	11.32×10^{-7}	755	7.06×10^{-3}	8.73×10^{-3}	115	0.0946	146

Table 2.—Rates of Evaporation of Organic Compounds

Run	Flow Rate cu.ft./min. Meter	Temp. Meter °C.	Pressure at Meter mm. Hg	Evap'n Rate g.moles/sec.	Pressure at sample mm. Hg	$\rho H^2 V$	ψ	$1/\psi$	ϕ	N_{Re}
				P-dichlorobenzene Temperature 35° C.						
D-9	0.365	22.8	750	18.57×10^{-7}	749	7.05×10^{-3}	8.61×10^{-3}	116	0.1132	154
D-16	1.090	22.8	753	29.23×10^{-7}	749	2.12×10^{-2}	2.86×10^{-3}	349	0.0591	460
D-17	1.863	22.6	752	30.47×10^{-7}	740	3.61×10^{-2}	1.681×10^{-3}	594	0.0359	785
D-18	2.843	22.6	751	37.44×10^{-7}	722	5.51×10^{-2}	1.101×10^{-3}	907	0.0282	1200
D-20	3.722	24.7	744	46.73×10^{-7}	690	7.08×10^{-2}	8.57×10^{-4}	1166	0.0262	1540
				Camphor—Temperature 45° C.						
C-4	0.344	23.7	758	6.45×10^{-7}	758	6.71×10^{-3}	7.82×10^{-3}	128	0.0544	141
C-7	0.680	25.0	756	7.70×10^{-7}	754	1.316×10^{-2}	3.99×10^{-3}	250	0.0330	276
C-12	3.701	26.4	751	16.40×10^{-7}	698	7.10×10^{-2}	7.40×10^{-4}	1351	0.0120	1486
R-C-3	1.226	25.8	746	8.85×10^{-7}	741	2.33×10^{-2}	2.25×10^{-3}	444	0.0210	489
R-C-5	2.151	22.2	735	12.85×10^{-7}	719	4.07×10^{-2}	1.29×10^{-3}	773	0.0169	855
				Maleic Anhydride—Temperature 45° C.						
M-2	0.734	24.3	759	17.46×10^{-7}	755	1.42×10^{-2}	5.61×10^{-3}	178	0.0844	299
M-5	3.734	25.2	751	29.56×10^{-7}	697	7.18×10^{-2}	1.109×10^{-3}	902	0.0260	1500
M-6	2.844	25.3	751	24.50×10^{-7}	724	5.46×10^{-2}	1.46×10^{-3}	685	0.0295	1147
M-9	1.962	23.0	757	20.92×10^{-7}	744	3.82×10^{-2}	2.08×10^{-3}	479	0.0370	802
M-11	0.370	22.7	756	12.85×10^{-7}	755	7.19×10^{-3}	1.108×10^{-2}	90.2	0.1228	151
				Phenol Temperature 35° C.						
P-1	1.234	23.9	755	12.19×10^{-7}	750	2.39×10^{-3}	2.98×10^{-3}	334	0.0431	520
P-4	0.471	23.5	755	8.77×10^{-7}	754	9.15×10^{-6}	7.80×10^{-3}	128	0.0812	199
P-6	1.996	22.9	752	14.01×10^{-7}	739	3.86×10^{-3}	1.85×10^{-3}	540	0.0302	840
P-7	2.979	21.9	752	16.85×10^{-7}	721	5.76×10^{-3}	1.24×10^{-3}	807	0.0237	1260
P-8	3.683	22.0	751	19.83×10^{-7}	699	7.15×10^{-3}	9.98×10^{-4}	1001	0.0218	1558
				Acetamide Temperature 45° C.						
A-1	1.216	25.0	750	2.21×10^{-7}	745	2.33×10^{-7}	3.865×10^{-3}	258	0.0284	489
A-2	0.494	25.8	750	1.67×10^{-7}	749	9.54×10^{-8}	9.54×10^{-3}	105	0.0535	198
A-3	0.303	25.0	751	1.41×10^{-7}	750	5.84×10^{-8}	1.542×10^{-2}	64.8	0.0733	122
A-5	2.575	24.9	756	2.69×10^{-7}	734	4.98×10^{-7}	1.81×10^{-3}	552	0.0160	1042
A-6	3.616	24.7	756	3.69×10^{-7}	706	6.99×10^{-7}	1.29×10^{-3}	775	0.0150	1466
				Camphene Temperature 35° C.						
C-2-1	1.224	24.8	753	66.57×10^{-7}	748	2.36×10^{-2}	2.55×10^{-3}	444	0.0485	513
C-2-2	0.471	24.8	753	43.14×10^{-7}	752	9.08×10^{-3}	5.86×10^{-3}	171	0.0822	198
C-2-6	2.564	23.5	752	90.92×10^{-7}	730	4.95×10^{-2}	1.073×10^{-3}	930	0.0308	1079
C-2-7	3.671	24.0	752	116.80×10^{-7}	700	7.08×10^{-2}	7.51×10^{-4}	1330	0.0265	1540
C-2-8	0.150	25.3	754	37.93×10^{-7}	753	2.90×10^{-3}	1.835×10^{-2}	54.5	0.0226	63

pressures of the solids were inaccurate.

The most plausible explanation conceived to date is dependent on the slip of the gaseous medium over the solid surface. Meyer (8) showed the existence of slip in small capillaries and suggested that the motion of the gas is the same as if the wall were moved back a distance, ϵ, where ϵ is termed the slip coefficient. If this suggestion is used in the present study, it may be assumed that the air is moving or slipping in direct contact with the solid and so increases the tendency to vaporize. The difference in the behavior of each solid might be explained by the variation in slippage among the compounds.

It is interesting to observe in Figure 3 the effect of temperature on the correlation of data for naphthalene. It is shown that the same plot represents the data for temperatures ranging from 35-55° C., as is suggested by the theoretical equation.

$$\phi = K\psi^{2/3}$$

This fact lends support to the proposed theory and suggests that the percentage saturation of solids in viscous air streams in a given apparatus at a given flow is proportional to the diffusivity raised to the two-thirds power.

Similar results to those found in these experiments were obtained by Linton and Sherwood (9) in their measurements of the rate of solution of solids into viscous water streams. In their experiments, however, it was found that the data agreed more closely with the Lévêque equation.

Acknowledgment

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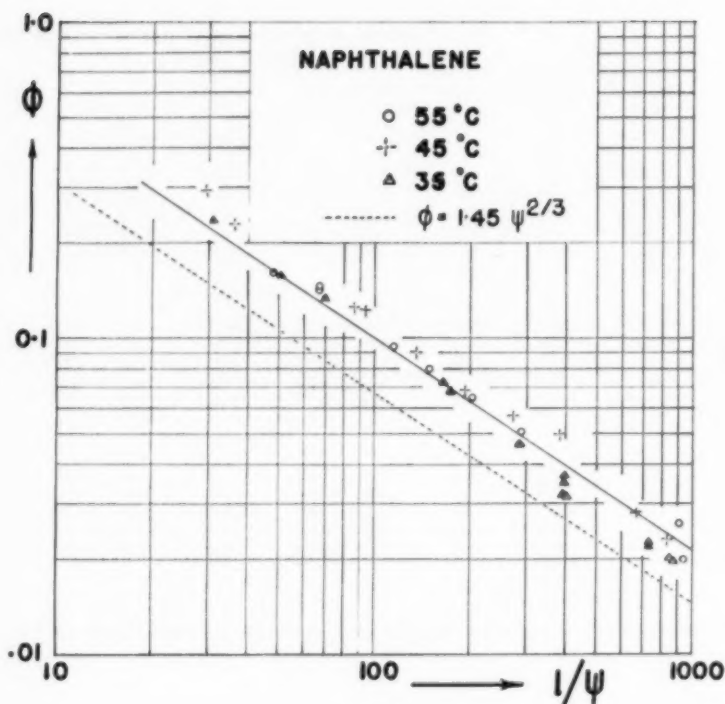
Fig. 4.
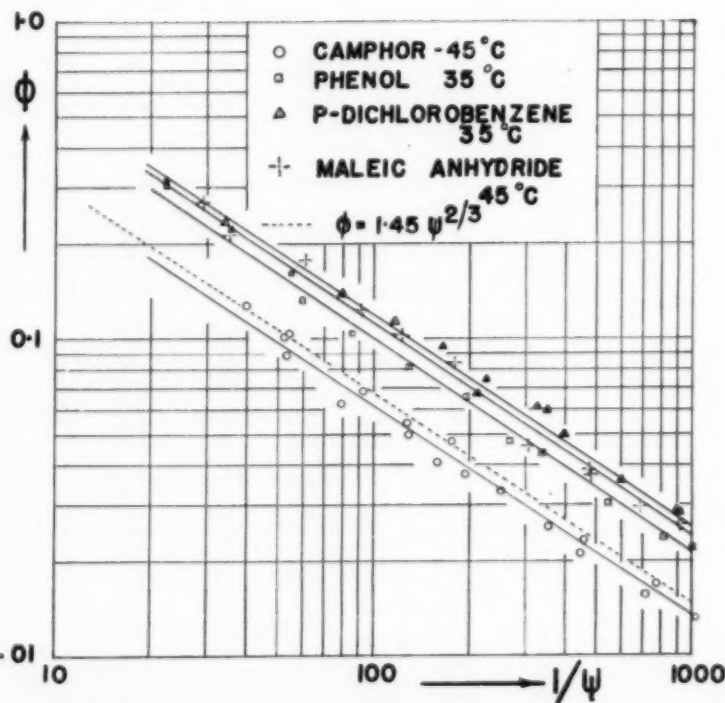
Fig. 5.

During the course of tin-plate corrosion-resistance investigations at the U. S. Steel Co.'s research and development laboratory, it became apparent that relatively minor deviations in processing could result in significant differences in corrosion resistance as measured by the prune-pack test (7). In the present paper one of a series of tests designed to establish the sources of variation in prune-pack results will be described.

It is not the intention of the authors to record the metallurgical findings of this experiment, but rather to report the design of the experiment in sufficient detail so that emphasis is placed on the many sources of variation that can influence test results; and a mathematical treatment of the results is presented to illustrate the kinds of conclusions that can be drawn. Chemical, metallurgical, and other engineers will recognize the similarity of this problem to many that confront them, especially in the field of industrial research.

To understand the scope of this one experiment, it is necessary to visualize the various steps in the manufacture of tin plate. These are indicated in Figure I. The manufacture of electrolytic tin plate is usually referred to as a continuous operation because in many of the processing steps, coils of thin steel two miles long, weighing a minimum of six tons, are welded end-to-end to effect a continuous ribbon. However, the coil is the fundamental unit, and its identity is maintained throughout the numerous processing steps. For a single experiment, a number of such coils must be produced. More detailed descriptions of the manufacture of tin plate are given in a number of texts and publications (2, 3, 4, 6, 8).

The present experiment proposed an investigation of the effect of four pickling treatments on corrosion resistance.* Furthermore, it was desired to evaluate the effect of pickling treatments at two levels of annealing. Each identifiable condition of a particular factor is referred to as a level of that factor.

Because of the large size of the coils of tin plate, the proper choice of test samples presents a problem. Experience has shown that variations occur from coil to coil, from one end of the coil to the other, from one edge of the coil to the other edge, and from test to test can. Some variations might be systematic, others, chance. With all these recognized sources of variations, how can one be sure that he is measuring the effects of pickling and of annealing?

* Pickling treatments refer to the pickle just before electroplating.

Evaluation of Several Sets of Constants and Several Sources of Variability

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The experimental design for this test is given in Figure 2. Each pickling treatment was repeated on three coils for each anneal. Each coil was sampled at nine locations as shown. Fifteen cans were made from the tin plate at each of the nine coil areas and were packed with prunes. The packed cans were stored at constant temperature (100° F.) and were examined at weekly intervals for evidence of "failure." A can failed when sufficient hydrogen was developed by reaction of the prunes with the tin plate to just bulge the end of the can. As packed, a can is under a relatively high vacuum and its ends assume a concave position. The time to reach failure is termed the "pack life."

Mathematical Description of a Mixed Model Factorial Experiment

Because of the complexity of the experiment actually performed, a simpler one will be discussed first. This imaginary experiment will be sufficiently complicated to illustrate a few general principles, and the method will then be extended to the actual experiment.

Development of the Mathematical Model on the Basis of a Simplified Experiment

Suppose an experimenter wished to investigate only the effects on pack life of Anneal 1 vs. Anneal 2. To do this three coils are tested at each anneal, each coil is sampled at two locations, the head and tail, and two cans are made from each coil location. There is a suspicion that different coils may give cans of differing pack life, even with the same annealing treatment. However, it is believed that if Anneal 1 is better than Anneal 2, this superiority will be the same for any coil. (Since coils cannot be split in this experiment, each coil must be run at a single anneal.) Finally, one wants to detect and to estimate any systematic difference in pack life between cans from the heads and tails of coils. Naturally, it will be useful to know whether this head-to-tail difference is constant; whether it varies from coil to coil; and whether it differs from an-
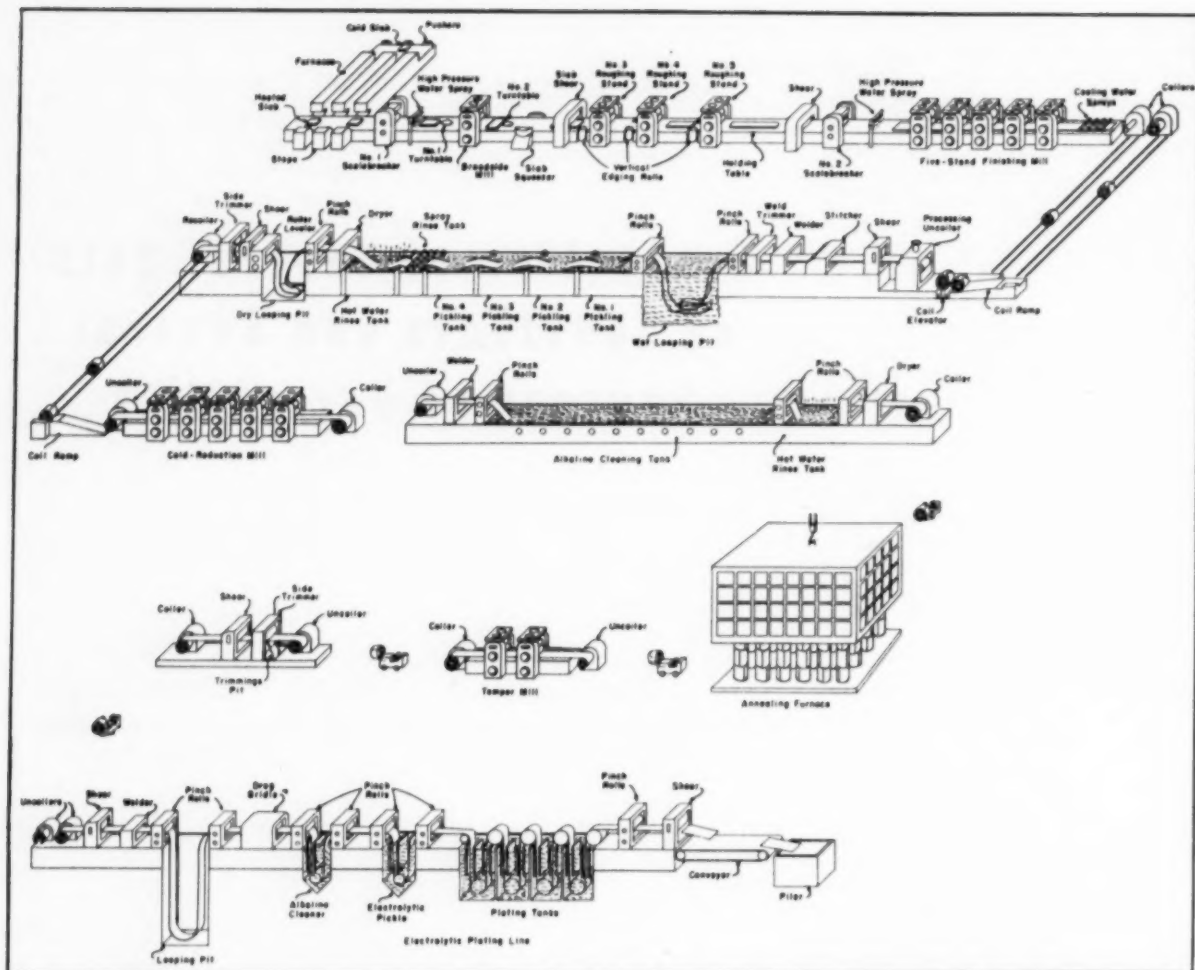
Fig. 1. Sequence of manufacturing operations for tin plate.

neal to anneal. It is taken for granted that there are other (unknown) factors operating that will produce variation in pack life for cans made from the same section of a single coil. Figure 3 describes this imaginary experiment graphically.

The balanced array of data implied by Figure 3 brings with it more advantages than the obvious one of giving information over a wide range of conditions. The calculation of the effects of the various factors, together with the corresponding tests of significance and confidence intervals, all become quite simple. Less expected is the practicability of using *all* the measurements in judging *each* effect; thus great gains in precision are obtained at no sacrifice of validity.

The situation is described in terms of a mathematical model in the simplest possible way. The mathematical treatment is based on the assumption that the actual pack life of a single can is the sum of *six* effects. These six effects are all in the form of linear additive "corrections" to the general average pack life:

1. Anneal Effect.

Two constants of equal absolute value, one positive and one negative, will describe the average effect of anneal on pack life. If the calculated difference between these constants is significantly greater than zero, the presence of the anneal effect is indicated.

2. Coil Effect.

A different value will be required for each coil, and the sum of these values will be zero in the long run. Variations among coils treated alike are due to unknown causes. Values for individual coils are not of interest; it is their scatter that is important. The values are, then, only particular sample values of a random variable. This scatter will be estimated as a standard deviation.

	Anneal I	Anneal II
Pickle A	3 Coils	3 Coils
Pickle B	3 Coils	3 Coils
Pickle C	3 Coils	3 Coils
Pickle D	3 Coils	3 Coils
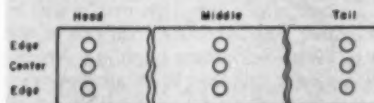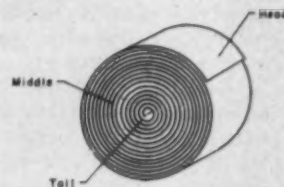
Location of samples on each coil

DESIGN OF THE EXPERIMENT

Fig. 2.

Anneal Effect a_i^A **Location Effect** a_k^L **Coil Effect** a_{ij}^C

2 Groups / 1 Comparison   2 Groups / 1 Comparison   2 Groups of Three

A x L Effect a_{ik}^{AL} **C x L Effect** a_{ijk}^{CL} **Duplicate Cans** a_{ijkl}^D

4 Groups / 1 Comparison   6 Groups of Two   12 Groups of Two

GROUPING OF DATA FOR CALCULATING SIX EFFECTS
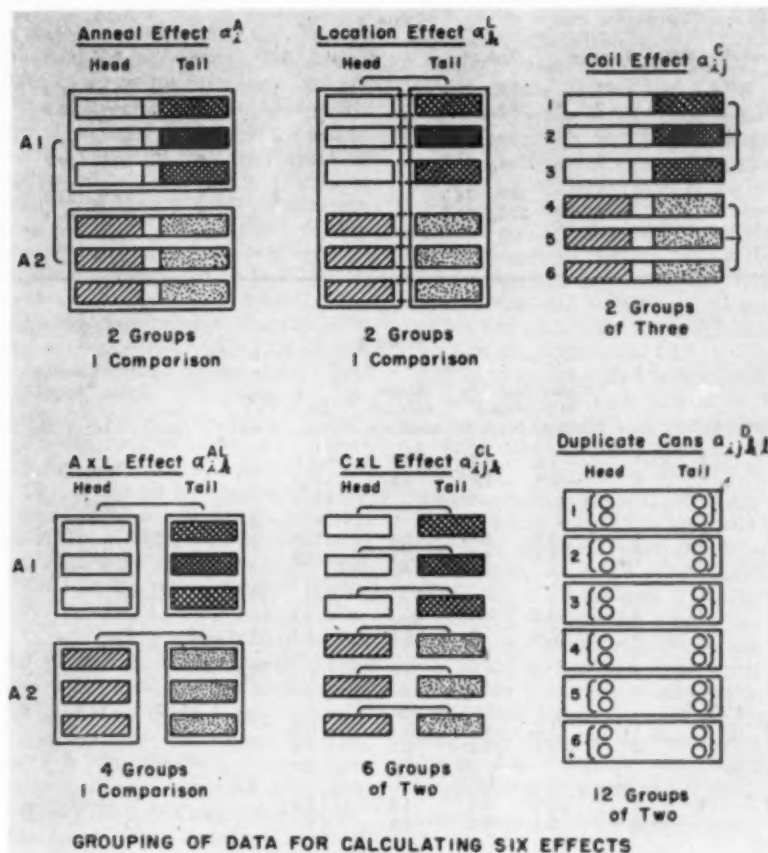
Fig. 3.

3. Location Effect.

Two constants of equal absolute value, one positive and one negative, will describe the effect of location within a coil.

4. Duplicate Test.

The effect of all (unknown) factors that produce different pack lives at the same location in a single coil is estimated in the same manner as the coil effect. The particular correction terms for the individual tests, whose long-run sum is

zero, are not useful; it is their scatter that is important. This scatter will be estimated as a standard deviation.

5. Anneal-by-Location Interaction.

If the anneal effect is not the same at the head locations as at the tail locations, a set of four constants (whose sum over anneals, or over locations is zero) will describe the situation.

6. Coil-by-Location Interaction.

A set of correction terms, to allow for the

possible failure of the location effect to be the same for different coils, is also required. Since these terms are due to unknown chance factors, their scatter will be estimated.

It might be thought that a set of additive constants should be included to allow for the possible failure of the anneal effect to be the same for different coils, and such an effect is indeed conceivable. But this effect cannot be isolated unless different parts of a single coil can be subjected to Anneal 1 and to Anneal 2. If there is such an effect, it will produce a greater scatter among the pack-life averages for single coils. In the language of statistical design, "the anneal-by-coil interaction is *confounded* with the coil main effect."

It is hoped, of course, that all or most of the terms in the last two sets enumerated will be small or even zero; if they turn out to be sufficiently small, they will probably be neglected.

It is worth reiterating that there are several objectives even in this simplified experiment. It is planned to estimate sets of constants for three effects and to estimate the measures of scatter for the three remaining effects. That there will be a real constant average difference in pack life between cans from coils annealed by the two methods is expected. Similarly, it is expected that heads will differ from tails systematically, that is, by a constant amount. Finally, if the head-to-tail difference is not quite the same for Anneal 1 as for Anneal 2, it is anticipated that the discrepancy will be a *constant*. Systematic effects which are measured by one or more constants are called Model I effects.

The persistent differences in pack life among coils treated alike are not of the same nature as Model I effects. Knowing the correction term exactly for one coil does not suffice for predicting the correction term for another, since coils differ for unknown reasons and in varying amounts. All one can do is estimate the scatter of pack life among coils treated alike. Similarly, the head-to-tail difference may vary somewhat from coil to coil and in a random manner. Again, we can only estimate the scatter of head-to-tail differences among coils. Chance effects of this type are called Model II effects. It will be noted that the effects listed previously as 1, 3, and 5 are Model I and effects 2, 4, and 6 are Model II.

Table 1 indicates the notation required. The symbol a (alpha) is used for each set of Model I effects to be evaluated. It is given a superscript (A or L) to show which factors are producing it, and subscripts to show all possible levels of each factor. The symbol a (italic type) with super- and subscripts is used in the same way for

Table 1

Factor	Superscript Abbrev.	Subscript	Effect	No. Levels
Anneal	A	i	a_i^A	2
Coil	C	j	a_{ij}^C	3
Location	L	k	a_k^L	2
Duplicates	D	l	a_{ijkl}^D	2
Ann.-by-Loc.	AL	ik	a_{ik}^{AL}	4
Coil-by-Loc.	CL	ijk	a_{ijk}^{CL}	12

those factors whose effects are to scatter the results (Model II).

The subscript combination ij required for the a^C because the single subscript j does not indicate for which anneal this is the j-th coil.

If μ is the grand average pack life of coils prepared half by Anneal 1 and half by Anneal 2, it is now possible to symbolize by $\mu + a_1^A$ the (true) pack life of cans made from coils of Anneal 1 and by $\mu + a_2^A$ the corresponding quantity for Anneal 2.

The true pack life of a particular coil, say the first one made at Anneal 1, is symbolized by

$$\mu + a_1^A + a_{11}^C \cdot$$

Since the head-to-tail effect is measured around the true coil average, the true pack life at the head ($k = 1$) of the second coil ($j = 2$), at Anneal 1 ($i = 1$) may be indicated by

$$\mu + a_1^A + a_{12}^C + a_1^L,$$

assuming for the moment that no interactions exist, that is, assuming that the three main effects completely describe the true situation. When all terms are put in, the value of the pack life obtained from the 1-th can at the k-th location of the j-th coil annealed at level i, is

$$x_{ijkl} = \mu + a_i^A + a_{ij}^C + a_k^L$$
$$+ a_{ik}^{AL} + a_{ijk}^{CL} + a_{ijkl}^D. \quad (1)$$

This repulsive-looking equation may discourage some engineers at first sight, but it is actually relatively simple. It is linear in all its terms, and all coefficients are unity.

For the sake of simplicity only three coils per annual were used and only two cans per location were tested. Table 2 gives a set of imaginary pack lines.

Inspection of these twenty-four numbers suggests several conclusions:

1. **There seems to be quite close agreement between duplicate cans, the average discrepancy being about one unit.**

2. **Cans from a single coil appear to cluster fairly well, but the differences among coils treated alike may be quite large.**

3. **Cans from location 1 (heads) give consistently higher pack lives than those from location 2 (tails).**

4. **The difference in pack life between anneals is not clear cut, although Anneal 1 appears to give somewhat greater pack life than does Anneal 2.**

It is not easy to see from Table 2 whether the head-to-tail difference is consistent from coil to coil, or from anneal to anneal. Now it is necessary to show how to use the data efficiently to make objective statements with predetermined risk of error, corresponding to the

guesses just given. It should be noticed that all the data are used in drawing each conclusion. This is possible because of three conditions:

1. **Data were taken in a fully balanced array.**

2. **Linear, additive relations hold for all six sets of effects.**

3. **The scatter among duplicate cans is roughly constant, as is the scatter among duplicate coils.**

The information in these data about the over-all effect of anneals is obtained by comparing the averages of the two sets of twelve, one for each anneal. The difference between these two averages may well be disturbed by chance factors, (for example, the pack lives for the three coils used for Anneal 1 may by chance have been higher than the pack lives for the three coils for Anneal 2), but is

not disturbed by the lumping of the data taken from different locations, since as many heads were used on Anneal 1 as on Anneal 2, and so also for tails.

Similarly, the over-all difference between heads and tails is not disturbed by the fact that half the data are from Anneal 1 material and half from Anneal 2 material. If the difference between heads and tails is not the same for Anneal 1 as for Anneal 2, there is said to be an anneal-by-location interaction ($A \times L$), and this also can be judged from the data.

Since we are primarily concerned with *differences*, it is simpler to code all the data by subtracting the same amount from each measurement. This is done in Table 3. It is simpler arithmetically to use the *sums* instead of the averages of various groups, and so these sums are also given in Table 3.

Table 2

Anneal	Coil	Location	Pack Life		Anneal	Coil	Location	Pack Life	
1	1	1	28.8,	29.5	2	1	1	31.0,	28.2
		2	27.8,	27.2			2	28.8,	28.7
	2	1	35.5,	36.9		2	1	30.3,	32.1
		2	33.6,	34.2			2	30.2,	29.7
	3	1	32.9,	34.3		3	1	29.9,	32.8
		2	32.0,	31.5			2	28.9,	28.4

Table 3

Ann.	Coil	Loc.	Coded Pack Life of Duplicates Original Minus 30		Range Between Duplicates	Can Sums	Coil Sums	Ann. Sums	Location Sums Loc. 1	Loc. 2
1	1	1	−1.2,	−0.5	0.7	−1.7				
		2	−2.2,	−2.8	0.6	−5.0				
							− 6.7			
1	2	1	5.5,	6.9	1.4	12.4				
		2	3.6,	4.2	0.6	7.8				
							20.2			
1	3	1	2.9,	4.3	1.4	7.2				
		2	2.0,	1.5	0.5	3.5				
							10.7			
								24.2	17.9	6.3
2	1	1	1.0,	−1.8	2.8	−0.8				
		2	−1.2,	−1.3	0.1	−2.5				
							− 3.3			
2	2	1	0.3,	2.1	1.8	2.4				
		2	0.2,	−0.3	0.5	−0.1				
							2.3			
2	3	1	−0.1,	2.8	2.9	2.7				
		2	−1.1,	−1.6	0.5	−2.7				
							0.0			
								− 1.0	4.3	−5.3
									22.2*	1.0*

* Location sums for both anneals together.

In the column headed Anneal Sums in Table 3, it may be seen that the overall difference in pack life due to differing annealing treatment is $(24.2 - (-1.0))/12$, or 2.10 weeks. An objective method is needed for judging the magnitude of difference that might turn up because of chance, say, one time in twenty—the chance that, for example, (coils varying as widely as they do even when treated alike) high-value coils might have been allocated to Anneal 1, and low-value coils to Anneal 2. The data give the necessary information in the form of the observed scatter of coil-averages (for coils treated alike). This scatter, expressed as a standard deviation, is 2.45,* with four degrees of freedom." The number of degrees of freedom for a measure of scatter is the number of independent estimates available, and for two sets-of-three measurements; this is four (two from each set). The result is that one can be 95 per cent certain that the true difference lies in the range $2.10 \pm 2.78 \times 2.45 \sqrt{2/3} = 2.10 \pm 5.57$. (The factor 2.78 is the "t" value taken from a table, with appropriate number of degrees of freedom. The factor $\sqrt{2/3}$ reflects the fact that allowance is made for the possible variability in the difference between two numbers, each the average of three-coil averages.) Thus the true difference between anneals may be zero. Hence no proof exists that there is a real difference in pack life between materials annealed by these two methods. However, the real difference lies, with 95 per cent certainty, between -3.47 and 7.67 weeks.

The observed difference in pack life between heads and tails is, from Table 3, $22.2-1.0/12$, or 1.77 weeks. This observed difference is almost the same as that between anneals, but it by no means follows that it is to be judged by the same criterion of precision. The location effect is judged *within* coils, and thus is free from the coil-to-coil scatter just mentioned. Of course, if the true head-to-tail difference varies from coil to coil, then it will be necessary to use this variability in judging the reality of the over-all head-to-tail difference. In statistical language if there is a coil-by-location interaction ($C \times L$), it must be used to judge the significance of the observed location effect. The data give us information on this point, as will be shown. The standard deviation found is 0.515. The result is that the true head-to-tail difference lies, with 95% confi-

* This number is calculated from the two sets-of-three coil sums given in Table 3. Thus, one takes the square root of the quantity:

$\frac{1}{64}\{(-6.7 - 8.1)^2 + (20.2 - 8.1)^2 + (10.7 - 8.1)^2 + (-3.3 + 0.3)^2 + (2.3 + 0.3)^2 + (0.0 + 0.3)^2\}$.

dence, in the range $1.77 \pm 2.78 \times 0.515 \times \sqrt{2/6} = 1.77 \pm 0.83$.

Thus the true difference lies, with 95% confidence, in the range 0.94 to 2.60. There is a real difference in pack life between heads and tails although, from the small amount of data available, its value cannot be precisely estimated.

The scatter among coils treated alike is also estimable, within limits, from the data. Although, as indicated above, the observed standard deviation among coils is 2.45, it can only be said that the true standard deviation lies, with 95% confidence, in the range 1.6 to 5.4.*

The mean square scatter among duplicate cans from the same location in a coil is computed to be 1.04, corresponding to a standard deviation of 1.02 weeks.

Two interactions ($A \times L$ and $C \times L$) remain to be discussed. The former is a Model I, or systematic effect, the latter is a Model II, or chance effect. Again with the use of all the data, Table 4 is constructed to see whether a set of correction terms is needed to allow for some inconsistency in the head-to-tail difference as between anneals. Average values are used below for greater intelligibility, although the four corresponding *sums* would be used in routine calculation to avoid difficulties of rounding.

Table 4

| | Location | | Difference between Location 1 and 2 |
	1	2	
Anneal 1	2.98	1.05	1.93
Anneal 2	0.72	−0.88	1.60
Avg.	1.85	0.08	1.77

The observed head-to-tail difference for Anneal 1 is 1.93, and for Anneal 2, 1.60. The discrepancy is then 0.33 weeks, which measures the failure of the head-to-tail difference to be the same for the two anneals. This is clearly so small as to be unimportant.

Since the $C \times L$ interaction is a Model II effect, it must be expressed as a scatter (mean or root mean square). It is calculated as the scatter of observed head-to-tail differences around the average head-to-tail difference for coils treated alike.† It turns out that the head-to-tail differences agree better

* The method of calculation for this interval can be found in any statistical text, e.g., references 1 and 5. The slight inflation due to the $C \times L$ scatter has been ignored here.

† This number is calculated from the two sets-of-three head-to-tail differences, as the square root of

$\frac{1}{32}\{(3.3 - 3.9)^2 + (4.6 - 3.9)^2 + (3.7 - 3.9)^2 + (1.7 - 3.2)^2 + (2.5 - 3.2)^2 + (5.4 - 3.2)^2\}$.

from coil to coil than we would expect. This is pure happenstance, but it means that a standard deviation need not be calculated for $C \times L$.

Summarizing these results in mathematical language, one can evaluate the constants of Equation (1) as follows:

1. $a_1{}^A$ or anneal effect. $a_1{}^A = -a_2{}^A = 0$ (actually $\frac{2.10 \pm 5.57}{2}$)

2. $a_{ij}{}^C$ or coil effect. Estimated standard deviation of $a^C{}_{ij} = 2.5$

3. $a_1{}^L$ or location effect. $a_1{}^L = -a_2{}^L = \frac{1.77 \pm 0.83}{2}$

4. $a_{1b}{}^{AL}$ or anneal-by-location interaction. $a_{1b}{}^{AL} \approx 0$

5. $a_{ijb}{}^{CL}$ or coil-by-location interaction. Estimated standard deviation of $a_{ijb}{}^{CL} \approx 0$

6. $a_{ijbl}{}^D$ or duplicate test. Standard deviation of $a_{ijbl}{}^D = 1.0$

In terms of the metallurgical problem, the findings are:

1. No evidence of a real difference in pack life between anneals. This experiment was not sensitive enough to detect a small difference.

2. A larger variability among coils than among duplicate cans, or within coils. Thus, more coils must be used to increase the precision of measurement of any effect that influences whole coils. Taking more cans within coils will hardly improve precision at all.

3. A consistent head-to-tail difference of 1.77 ± 0.83 weeks.

4. Anneal, location, and coil-to-coil effects additive and independent. This is justified by the absence of any large interactions.

The preceding paragraphs of this paper described an imaginary experiment. It was, in statistical jargon, a $3 \times 2 \times 2$ Mixed Model factorial experiment (*three* coils, at each of *two* Anneals, *two* Locations).

Mathematical Treatment of the Actual Experiment

The actual experiment followed the pattern of a Mixed Model factorial, to study two anneals, four methods of pickling, head-middle-tail differences, three sheet positions (edge-center-edge), using three coils per anneal-pickle combination, and fifteen cans per spot. It required then $2 \times 4 \times 3 \times 3 \times 3 \times 15$ or 3,240 cans. The model equation, corresponding to Equation (1), was, of course, somewhat more complicated. Advantages in the ability to generalize were, however, correspondingly great, since each over-all effect could be judged precisely as to magnitude, and also examined as to consistency under widely varying conditions.

Table 5 (corresponding to Table 1) gives the necessary information for writing the model equation. The equation

Table 5

Factor	Superscript Abbrev.	Subscript	Effect	No. of Levels	Remarks
Anneals	A	i	a_i^A	2	As before
Pickles	P	j	a_j^P	4	In two pairs
Positions	E	k	a_k^E	3	Edge-center-edge
Locations	L	l	a_l^L	3	Head-middle-tail
Coils	C	m	a_{ijlm}^C	3	
Duplicates	D	n	a_{ijklmn}	15	

$$x_{ijklmn} = \mu + a_i^A + a_j^P + a_k^E + a_l^L + a_{ijlm}^C + a_{ijklmn}^D + a_{ij}^{AP} + a_{ik}^{AE} + a_{il}^{AL} + a_{jk}^{PE}$$
$$+ a_{jl}^{PL} + a_{kl}^{EL} + a_{ijlm}^{BC} + a_{ijklm}^{LC} + \text{higher order interactions} \quad (2)$$

Table 6.—Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	Expected Values of Mean Squares
Anneals (A)	1	219	219. *	$S + 108\sigma'^2_A$
Pickles (P)				
Between two pairs	1	259	259. *	$S + 54\sigma'^2_P$
Within pairs	2	6	6.	
Positions (E)				
Between edges avgd. and center	1	121	121.	$R + 72\sigma'^2_E$
Between two edges	1	2	2.	
Locations (L)				
Linear	1	122	122. *	$Q + 72\sigma'^2_L$
Quadratic	1	0	0.	
Coils (C)	16	212	13.2°	$Q + 3\sigma_{CE}^2 + 9\sigma_C^2 = S$
Interactions				
A × P	3	39	13.0	$S + 27\sigma'^2_{AP}$
A × E	2	5	2.5	$R + 36\sigma'^2_{AE}$
A × L	2	40	20.0°	$Q + 36\sigma'^2_{AL}$
P × E	6	20	3.3	$R + 18\sigma'^2_{PE}$
P × L	6	41	6.9	$Q + 18\sigma'^2_{PL}$
E × L	4	27	6.8	$\sigma_D^2 + \sigma_{CLE}^2 + 24\sigma'^2_{EL}$
C × E	32	43	1.3	$\sigma_D^2 + \sigma_{CLE}^2 + 3\sigma_{CE}^2 = R$
C × L	32	88	2.7°	$\sigma_D^2 + \sigma_{CLE}^2 + 3\sigma_{CL}^2 = Q$
A × P × L	6	17	2.8	$Q + 9\sigma'^2_{APL}$
A × P × E	6	12	2.0	$R + 9\sigma'^2_{APE}$
A × L × E	4	2	0.5	$\sigma_D^2 + \sigma_{CLE}^2 + 12\sigma'^2_{ALE}$
P × L × E	12	23	1.9	$\sigma_D^2 + \sigma_{CLE}^2 + 6\sigma'^2_{PLE}$
C × L × E	64	64	1.0	$\sigma_D^2 + \sigma_{CLE}^2$
A × P × L × E	12	23	1.9	$\sigma_D^2 + 3\sigma'^2_{APLE}$
Duplicates	3024	4050	1.34	σ_D^2
Totals	3239	5435		

* Significant at the 0.05 level.

The absence of any large interactions, except $A \times L$, permitted drawing several conclusions of considerable breadth:

1. The difference in pack life between Anneal 1 and Anneal 2 had an average value of 2.0 ± 1.0 weeks.

2. The four pickles were of two general types. The difference between types was large, consistent for both anneals, at all locations, and at both edges and centers. The differences within pickle types were negligible.

3. The difference in pack life within the coils from head to tail was 1.4 ± 0.4 weeks for Anneal 2, and 0.4 ± 0.4 for Anneal 1.

4. The difference in pack life between the edges and the middle of coils was 1.6 ± 0.3 weeks, the middle being higher.

5. There were real differences among coils treated alike. Increased precision in estimating effects that influence whole coils can only be attained by using a larger number of coils. Considering the relative costs of sampling cans and coils, the optimum number of cans per coil is about 45.

6. It is worth emphasizing that each of these conclusions uses all the data and each holds at all levels of all the other factors varied.

Summary

Same basic statistical principles have been applied to an experiment designed to study the simultaneous impact of a considerable number of factors. The principle of *balance* has been emphasized because it permits conclusions of maximum generality and because all the data can be used in drawing each conclusion, thus giving results of maximum precision.

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itself is a necessary part of the statistical handling of the data. The statistical method used is called the Analysis of Variance, and the results are tabulated in Table 6.

(For convenience in reading, all numbers in the last three columns of Table 6 have been divided by 15, the number of cans measured at each spot. The symbol σ_D^2 refers to the variance of means of 15 cans all from the same spot.) The rationale of the analysis of variance for Mixed Model problems is outlined in "General Theory of Evaluation of Sets of Constants and Sources of Variability," by Henry Scheffé, to appear in an early issue of C.E.P.

There are simple rules for writing down the possible interactions. As Equation (2) indicates, the experiment was designed to estimate not only the six main effects (four sets of constants and two mean squares or variances), but also eight types of consistency (or inconsistency) of each effect at the various levels of the other factors.

As it turned out, all the two-factor interactions except $C \times L$ and $A \times L$ were negligible. The former was small but was detected because of the large amount of data available. The latter was large, and expected. It had been anticipated that the head-to-tail difference would be larger at Anneal 2 than at Anneal 1.

Interfacial Resistance

A Study of Gas Absorption in Falling Liquid Films

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Background and Theory

The rate of mass transfer through a liquid may be conveniently represented by the relation

$$N_A = k_L(A_i - A_o) \qquad (1)$$

where A_i is the concentration of the solute at the transfer interface, A_o is the concentration of the solute in the bulk of the liquid, and N_A is the rate of transfer of solute A in moles per unit time per unit area of transfer surface. The liquid-film coefficient k_L is commonly selected on the basis of laboratory or pilot-plant data, and this paper is concerned with the theoretical prediction of this quantity.

The concept of the over-all driving force, while useful to the design engineer, is probably unrealistic; the true physical situation may be expressed by the equation

$$N_A = D_A \left(\frac{\partial A}{\partial x} \right) \qquad (2)$$

where D_A is the diffusion coefficient of A through the liquid, and x is the space coordinate into the liquid layer. ·

Lewis and Whitman (12) postulated that there is a stagnant film next to the surface of a liquid layer, that the remainder of the layer is well enough mixed so that the concentration gradient is restricted to the stagnant film, and that there is no accumulation of material in the film. This leads to the conclusion that

$$k_L = \frac{D_A}{x_F} \qquad (3)$$

where x_F is the thickness of the stagnant film. As this thickness cannot be predicted, the use of the Whitman film

Rippling may be eliminated in a falling liquid film by the addition of wetting agents. Data on absorption and desorption of oxygen and carbon dioxide in water containing a wetting agent agree to within 5 to 25% with a theoretical equation describing unsteady-state diffusion in the flowing liquid. This relation was developed assuming equilibrium at the interface, a parabolic velocity distribution in the falling film, uniform initial concentration, and no waves at the surface. The data compare favorably with those of Peaceman in wetted-wall columns so short that rippling had not begun.

Data for absorption in films in which rippling occurred are also presented and indicate, as expected, that mass-transfer rates are severalfold greater than those encountered when rippling is absent.

Interfacial resistance is suggested as an explanation for the deviation of experimental results for the nonrippling films from theory, as well as for the observed difference between absorption and desorption when rippling was present. The results indicate that only about one solute molecule of a million striking the interface is able to penetrate the phase boundary.

The transition from laminar to turbulent flow is shown to occur at a Reynolds number of about 1,200.

theory must be empirical. Furthermore, the stagnant-film theory predicts that k_L varies as the first power of the diffusivity, but data of Sherwood and Holloway (18) for a packed tower and of Peaceman (14) for a short wetted-wall column indicate that it varies as the square root of the diffusivity.

A more realistic notion of the process of absorption, and one that predicts that k_L varies as the square root of the diffusivity,[1] was advanced by Higbie (9). He suggested considering the situation to be an unsteady-state process in which the concentration of solute at any place in the falling film is controlled by diffusion of molecules into and out of the section and by bodily transport of molecules owing to bulk motion of the film. Henceforth, the word *film* will be used

[1] This is true only for the limiting case of short time of contact.

to describe the entire liquid layer, not the hypothetical stagnant film of the Whitman theory.

Higbie's derivation is based on the following assumptions: (1) the falling film is in laminar motion, (2) the surface of the film is moving at a uniform velocity, (3) the interfacial concentration has a constant value A_o, and (4) the effect of diffusion in the direction of flow is negligible. The first of these assumptions requires that there be no ripples on the surface of the film and that the Reynolds number of the film be below the critical value at which turbulence begins. The second assumption is not seriously in error if the time of contact between liquid and gas is sufficiently short. If this is true, the diffusing molecules penetrate only a short distance into the film; as far as these molecules "know," the film has a uniform

velocity equal to the surface velocity. The third assumption is in error provided a resistance exists either in the gas phase or at the interface. Evidence to be presented later indicates that an interfacial resistance exists even though the gas-phase resistance may be eliminated. The fourth assumption has been shown mathematically by Peaceman (14) to be valid, except at exceedingly low velocities.

The solution of the differential equation resulting from these assumptions yields the following expression for the average value of k_L, defined in terms of the initial driving force by Equation (1):

$$k_L = 2 \sqrt{\frac{D_A}{\pi \theta}} = 2 \sqrt{\frac{D_A u_s}{\pi z}} \qquad (4)$$

where θ is the time of contact between gas and liquid, u_s is the surface velocity of the film, and z is the height of the column. The local value of k_L is one half the cumulative average value. For very short times of contact, this relation also applies for k_L based on the logarithmic-mean driving force.

If the time of contact is long enough for the diffusing molecules to penetrate completely to the solid wall, the velocity distribution in the liquid film must be considered, and not only the differential equation but also the boundary condition at the solid wall must be modified. Although the true velocity profile has not been definitely established, it seems probable that it is nearly parabolic, with a maximum velocity at the free interface and zero velocity at the solid-liquid interface. The investigations of Grimley (8) and of Friedman and Miller (7) suggest that ripples at the surface of the film may affect this assumption, but Grimley indicates that it is true when no ripples are present.

Pigford (16) obtained a solution for the differential equation

$$D_A \frac{\partial^2 A}{\partial x^2} = u_s \left[1 - \left(\frac{x}{B_F} \right)^2 \right] \frac{\partial A}{\partial z} \qquad (5)$$

representing the physical situation described. His result was

$$\frac{A_i - A_2}{A_i - A_1} = 0.7857 \exp{(-5.121p)} + 0.1001 \exp{(-39.31p)}$$
$$+ 0.0360 \exp{(-105.6p)} + 0.0181 \exp{(-204.7p)} + \ldots \qquad (6)$$

where

A_2 = average outlet concentration
A_1 = average inlet concentration
$p = D_A \theta / B_F^2$

where B_F is the actual film thickness. This expression may be used to calculate the mass-transfer coefficient $(k_L)_{\text{l.m.}}$ based on a logarithmic-mean driving force, since

$$(k_L)_{\text{l.m.}} = \frac{u_{avg} B_F}{z} \ln \frac{A_i - A_1}{A_i - A_2} \qquad (7)$$

For short times of contact this reduces to

$$\frac{A_2 - A_1}{A_i - A_1} = 3 \sqrt{\frac{D_A z}{\pi B_F^2 u_s}} \qquad (8)$$

which, expressed in terms of k_L based on a logarithmic-mean driving force, yields Equation (4), confirming the validity of the assumption of uniform velocity for very short times of contact.

The expression of this relation in terms of the mass rate of flow proves more useful and is

$$(k_L)_{\text{l.m.}} = \sqrt{\frac{6 D_A \Gamma}{\pi z \rho B_F}} \qquad (9)$$

where Γ is the rate of flow in mass per unit time per unit length of wetted periphery, and ρ is the liquid density.

If the time of contact is long, p becomes large, and all the terms in Equation (6) become negligible in comparison with the first. Then

$$(k_L)_{\text{l.m.}} = 3.41 \frac{D_A}{B_F} \qquad (10)$$

Since Equations (7), (8), (9), and (10) contain the film thickness, they cannot be used directly to predict transfer coefficients. Consideration of the characteristics of a falling liquid film will yield a relation for film thickness in terms of the mass-flow rate as shown by Fallah, Hunter, and Nash (6). The result is

$$B_F = \left(\frac{3 \mu \Gamma}{g \rho^2} \right)^{1/3} \qquad (11)$$

where μ is the viscosity. Also

$$u_s = \frac{3}{2} u_{avg} \qquad (12)$$

These relations, developed for a parabolic velocity distribution, assume that there is no slip at the wall boundary and that the density of the gas is negligible compared with that of the liquid.

Equation (11) has been confirmed

experimentally by Fallah, Hunter, and Nash (6), Cooper, Drew, and McAdams (2), and Friedman and Miller (7) by measurements of average film thickness, even when rippling occurs. Equation (12), however, is subject to some question when rippling is present, but Grimley (8) indicates that it holds in the absence of rippling.

In terms of the height of a transfer unit, Equation (9) for short times of contact becomes

$$H_L = \frac{\Gamma}{\rho (k_L)_{\text{l.m.}}} = \sqrt{\frac{\pi B_F z \Gamma}{6 \rho D_A}} \qquad (13)$$

and Equation (10) for long times of contact becomes

$$H_L = 0.29 \frac{\Gamma B_F}{\rho D_A} \qquad (14)$$

Equation (13) is based on an approximation to a logarithm, which renders it somewhat in error. If this approximation is not made, the equation must be written

$$H_L = \frac{z}{-\ln \left(1 - \frac{3}{\sqrt{\pi}} \sqrt{\frac{D_A \theta}{B_F^2}} \right)} \qquad (15)$$

and will give the same result as Equation (6) for much higher times of contact.

The preceding theory is dependent upon the absence of rippling, as rippling would cause some mixing near the interface, would change the interfacial area, and would affect the velocity distribution. It is an experimental fact that when a liquid falls along a vertical surface, wave formation begins at the free surface after several inches of travel, even though the Reynolds number may be far below the critical value. Kapitsa (10) presents a mathematical analysis demonstrating that the wave system is more stable than the laminar one and discusses the effect of surface tension on the amplitude, frequency, and shape of the wave profile. It has been shown by several investigators that this condition is not synonymous with actual turbulence, which does not appear until a Reynolds number slightly greater than 1,000.

The addition of a wetting agent to a falling liquid film decreases the rippling almost to elimination. This appears anomalous at first, since Grimley (8) and Kapitsa (10) have shown that the critical Reynolds number at which rippling begins increases with increasing surface tension, whereas the wetting agent decreases the surface tension. A possible explanation is that with a monomolecular layer of wetting agent on the surface, an attempt to form a ripple separates the wetting agent, exposing water (which has a higher surface tension) in the localized area and thus preventing further growth of the ripple. This would suggest that there should be an optimum concentration of wetting agent for obtaining a smooth film, which is in accordance with experimental facts that will be discussed later. The
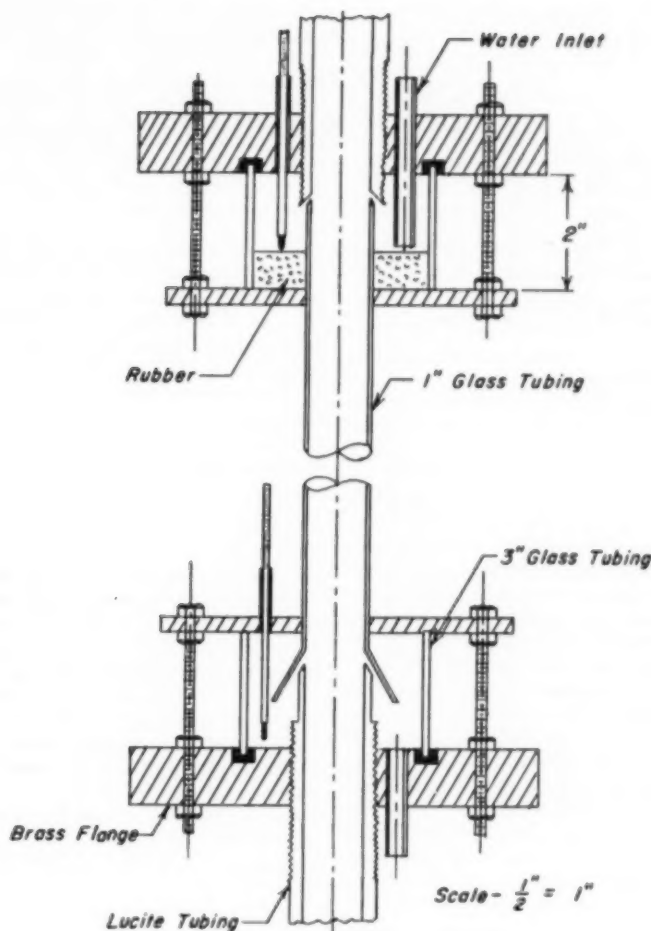
Fig. 1. Wetted-wall column assembly.

reason that a wetting-agent concentration greater than the optimum still reduces rippling to an extent may be due to a secondary effect, suggested by Lamb (11) for the suppression of ocean waves by oil slicks. In a multilayer film the surface tension is not constant if extensions and contractions occur. In fact when a wave begins, the tension increases enough to retard further development of the wave.

It has been suggested by Higbie (9) that the physical situation in a packed column may be represented by the unsteady-state diffusion theory, since he conceived of the liquid flowing in laminar fashion over each piece of packing, then being completely mixed before passing to the next. This constitutes a series of short contacts, during each of which Equation (4) would be obeyed. Peaceman (14) conducted an investigation in very short wetted-wall columns in order to approximate the time of

contact on a packing piece and to prevent rippling. The present investigation, on the other hand, was carried out both in a long wetted-wall column with wetting agent to prevent rippling and in a short column with and without wetting agent in an attempt to test the theory over a wide range of contact time.

Apparatus and Procedure

The longer wetted-wall column, constructed of 0.99-in. I.D. glass tubing, was 3.73 ft. long from the knife edge at the top to the beginning of the taper at the bottom. The column assembly, including inlet and outlet liquid reservoirs, is shown in Figure 1. The shorter column was similar in design and was made of 0.95-in. I.D. glass tubing which was 1.524 in. long. The upper calming section was 3 ft. long and constructed of 1-in. I.D. Lucite tubing. It was carefully machined, so that it formed a 45° upflow slot with the knife edge at the top of the glass column. Only one type of entrance

slot was used, since Peaceman (14) had tried various types of entrance slots and found no difference in mass-transfer rates. The lower calming section was 4.5 ft. long and was machined to form a 30° downflow slot with the tapered portion of the glass column at the bottom. The calming sections were threaded so that the widths of the slots might be adjusted. Thermometers were inserted in the inlet and outlet reservoirs and in the two extreme ends of the calming sections. The total volume of the upper liquid reservoir was about 60 cc.; that of the lower, about 100 cc.

The upper liquid reservoir was completely filled with liquid during operation and the liquid level in the lower reservoir was kept just below the exit slot to prevent any gas-liquid contact outside the wetted-wall column.

Close temperature control was maintained by passing the gas and liquid through a thermostatically controlled heat exchanger. Also, the room temperature was kept within 0.5° C. of the system temperature.

Flow rates were measured by rotameters, the liquid rotameter being placed downstream of the inlet sampling port. The flow of liquid in the inlet sampling side stream was continuous. The outlet sampling port consisted of the entire run-off from the column. Liquid from the sample ports entered the bottom of an Erlenmeyer sampling flask and spilled over the top. Operation was continued long enough for the volume of water in the sampling flasks to be displaced at least three times.

The inlet gas was bubbled through a water saturater to prevent transfer of water vapor in the wetted-wall column.

Analysis for dissolved oxygen in water was performed by a modification of the Winkler method (20), the accuracy being checked to within about 0.5% against I.C.T. values by analysis of both air- and oxygen-saturated solutions.

The analysis for carbon dioxide was accomplished by precipitating the carbon dioxide as barium carbonate by use of a mixture of barium chloride and standard sodium hydroxide. The excess sodium hydroxide was then titrated with hydrochloric acid to a phenolphthalein end point. Attempts to check saturated solutions with the I.C.T. values were unsuccessful, yielding results from 2 to 3% in error. It is believed that this was due to inability to prepare saturated solutions rather than to faulty analyses.

Mass-Transfer Results With No Rippling

The addition of a wetting agent produced a marked effect on rippling in the falling liquid films. Visual observation showed that an increase in the concentration of wetting agent was accompanied by a decrease in both the amplitude and frequency of the ripples. Continued addition of wetting agent, beyond the concentration at which ripples were not visible, caused the restoration of rippling, so that there existed an optimum concentration for the attainment of a smooth film, as suggested by the pro-

posed mechanism for the elimination of ripples. This was exemplified by the effect of this change in rippling on the height of a transfer unit, as shown in Figure 2. The optimum concentration of the most suitable wetting agent tested, Petrowet R,[1] was 0.30%, both at high and low Reynolds numbers.

Other investigators have found similar results. Ternovskaya and Belopolskii (21) investigated the effect of three wetting agents on the absorption of sulfur dioxide in water and found that one of these gave a pronounced maximum in H.T.U., despite the fact that the surface tension continued to decrease; a second caused a slight maximum; and the third caused an increase in H.T.U. up to a value which remained constant with increasing concentrations.

Sherwood and Holloway (18) used two different wetting agents in a packed tower with the foregoing result for both. The maximum value of the H.T.U. was the same regardless of the wetting agent used.

Previous wetted-wall-column data, as well as those of this investigation without wetting agent, have indicated that the rate of absorption is from 50 to 150% greater than that predicted by the theoretical relation, Equation (6). However, data of this investigation with wetting agent added agree much more closely than this with Equation (6), as shown in Figures 3 and 4. In fact, the carbon dioxide data indicate from 3 to 15% and the oxygen data from 10 to 25% less absorption than Equation (6) predicts.[2]

[1] Petrowet R, a product of Du Pont Co., is the sodium salt of saturated hydrocarbon sulfonates.

[2] In the calculation of this relation 1.95 $\times$ 10^{-5} sq. cm./sec. was used as the diffusion coefficient of carbon dioxide, and 2.56 $\times$ 10^{-5} sq.cm./sec. as that for oxygen.
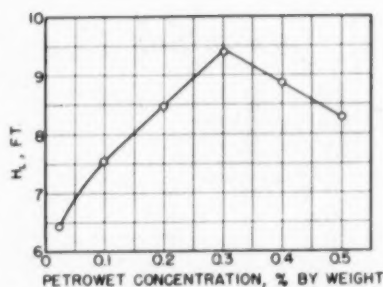
Fig. 2. Effect of wetting agent on H.T.U. for absorption of oxygen in water.

A statistical analysis of the data yielded the following results:

1. For oxygen absorption, with wetting agent, the average deviation of H_L was 1.0%, and the standard deviation, 3.2%, from the best line through the data. From this, one may predict that 99.7% of all prospective observations should be within ±10% of the curve.

2. For carbon dioxide absorption and desorption, the average deviation was 2.5%, and the standard deviation, 7.5%, from the best line through the data. From this, one may predict that 99.7% of all prospective observations should be within ±22% of the line, or 95.5% within ±15%.

3. The data of Peaceman (14) have an average deviation of 7.7% and a standard deviation of 11.0% from his best line. For these data, one may predict that 99.7% of all prospective observations should be within ±33% of the line, and 95.5% within ±22% of the line.

A generalized plot, intended to bring together data for various systems in columns of different lengths, is presented in Figure 5. The theoretical relation, Equation (6), is shown along with the asymptotes for short and long times

of contact, represented by Equations (13) and (14) respectively. The data of the authors and of Peaceman (14) are shown. The fact that all points fall above the theoretical curve suggests a resistance that has not been accounted for.

INTERFACIAL RESISTANCE

This additional resistance may be explained in terms of lack of thermodynamic equilibrium at the interface. If this is so, the transfer of molecules across an interface occurs at a finite rate and probably involves the formation of an intermediate activated state in accordance with classical reaction-rate theory. The process may result from the following steps:

a. $A(g) \rightleftharpoons A(g)(adsorbed)$

b. $A(g)(adsorbed) \rightleftharpoons A(l)$

Of the molecules that strike the surface, only those with energy sufficient to surmount the energy barrier involved will be dissolved. Orientation of the molecules may also play a part. As a result, only a fraction of the gas molecules which strike the interface penetrate it and become liquid molecules. This fraction is termed the *accommodation coefficient*.

According to the kinetic theory of gases, the number of moles of gas striking a unit area of surface per unit time is

$$M = \sqrt{\frac{1}{6\pi}} \, A_G \bar{u} \qquad (16)$$

where

A_G = concentration of A in the gas, lb.moles/cu.ft.

$\bar{u}$ = root-mean-square velocity of the gas molecules
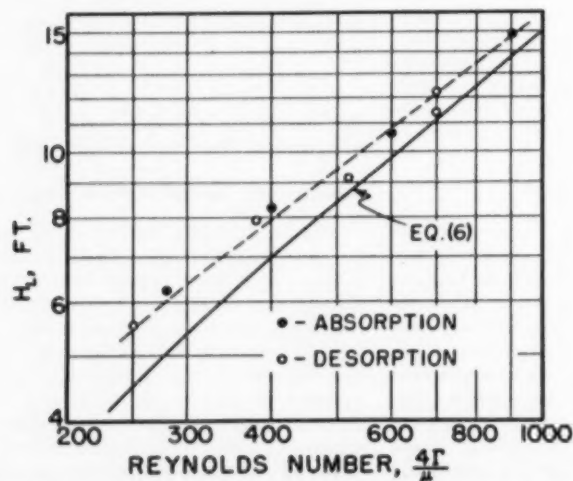
Fig. 3. Absorption and desorption of carbon dioxide with wetting agent, 3.73-ft. column, 0.99 in. I.D., 25° C.
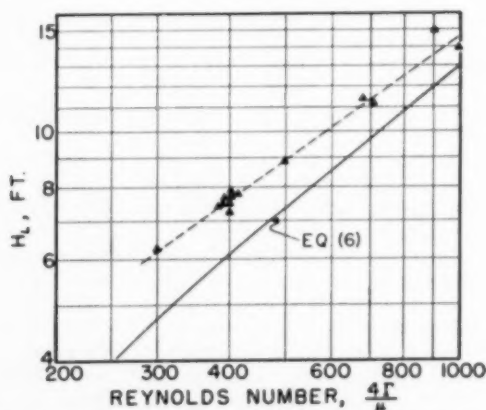
Fig. 4. Absorption and desorption of oxygen with wetting agent, 3.73-ft. column, 0.99 in. I.D., 25° C.

The number of pound moles entering the surface per unit area per unit time is

$$M_1 = \sqrt{\frac{1}{6\pi}} \, A_G \bar{u} a_1 \qquad (17)$$

where a_1 is the accommodation coefficient, i.e., the fraction of incident molecules that penetrate the interface.

Let

A_i = true concentration of A in the liquid at the interface, lb. moles/cu.ft.

A_G^* = fictitious gas-phase concentration of A that would be in equilibrium with A_i, lb. moles/cu.ft.

A_i^* = fictitious liquid-phase concentration of A that would be in equilibrium with the true gas concentration A_G, lb. moles/cu.ft.

Then the number of pound moles passing through the interface per unit area per unit time in the direction from liquid to gas is

$$M_2 = \sqrt{\frac{1}{6\pi}} \, A_G^* \bar{u} a_2 \qquad (18)$$

where a_2 is the accommodation coefficient for the molecules that are leaving. This equation follows from the principle that the rates of penetration and escape are equal at equilibrium. When $a_1 = a_2 = a$, the net rate of transfer of gas molecules across the liquid interface is

$$N_A = \frac{a\bar{u}}{\sqrt{6\pi}} (A_G - A_G^*) \qquad (19)$$

But the rate of transfer may also be expressed as

$$N_A = k_L(A_i^* - A_o) = k_L'(A_i - A_o) \qquad (20)$$

where k_L is the apparent liquid-film coefficient, and k_L' is the true liquid-film coefficient exclusive of the interfacial resistance.

By Henry's law,

$$A_G = HA_i^* \qquad (21)$$

and

$$A_G^* = HA_i \qquad (22)$$

where H is the Henry's law constant in lb.moles per cu.ft. in gas/lb.moles per cu.ft. in liquid. Substituting Equations (21) and (22) in Equation (19) and equating the result to Equation (20) gives

$$\frac{a\bar{u}H}{\sqrt{6\pi}} (A_i^* - A_i) = k_L'(A_i - A_o)$$
$$= k_L(A_i^* - A_o)$$
$$= k_i H(A_i^* - A_i) \qquad (23)$$

where k_i is a transfer coefficient for the interfacial resistance. From Equation (23)

$$\frac{1}{k_L} = \frac{1}{k_L'} + \frac{1}{k_i H} = \frac{1}{k_L'} + \frac{A_i^*}{aM} \qquad (24)$$

and

$$a = \frac{\sqrt{6\pi} k_i}{\bar{u}} \qquad (25)$$

Thus values of the accommodation coefficient a may be calculated from the experimental data. A more complete theory resulting from the solution of the diffusion equation for short times of contact and accounting for the variation of A_i with time has been developed. However, values of accommodation coefficient calculated from this theory do not give sufficiently different results to warrant its inclusion, since it cannot be used at all for long times of contact.

Baron (1) has recently developed a theoretical relation by absolute reaction-rate theory, for predicting accommodation coefficients, which will be presented in a forthcoming paper. The values of a predicted by this theory are listed in Table 1, which also includes a summary of the experimentally determined accommodation coefficients. The table also includes values of a calculated from the data of Peaceman (14), which were taken in very short wetted-wall columns, from the data of Higbie (9) [calculated by Danckwerts (4)], in which absorption occurred from a stationary gas bubble to a liquid film flowing around it, and from the data of Manogue (13), who absorbed carbon dioxide into a short, laminar jet of water.

Table 1.—Summary of Accommodation Coefficients

Absorption and desorption of CO_2 in H_2O with wetting agent, 3.73-ft. column, 25° C.

Re	a(expt'l.)	a(theor.)(1)
300	1.8×10^{-6}	
500	3.3×10^{-6}	1.9×10^{-6}
800	7.4×10^{-6}	

Absorption and desorption of O_2 in H_2O with wetting agent, 3.73-ft. column, 25° C.

300	3.7×10^{-6}	
500	5.9×10^{-6}	3.9×10^{-6}
800	9.1×10^{-6}	

Desorption of CO_2 in H_2O without wetting agent, 4-cm. column, 25° C. (from data of Peaceman)

75	3.0×10^{-6}	
300	8.5×10^{-6}	1.9×10^{-6}
500	14.5×10^{-6}	

1 cm. column

75	2.0×10^{-6}	
300	6.0×10^{-6}	1.9×10^{-6}
500	10.2×10^{-6}	

Absorption of CO_2 in H_2O, 6-cm. long jet, 25° C. (from data of Manogue)

a(expt'l.)	a(theor.)(1)
12×10^{-6}	1.9×10^{-6}

Absorption of CO_2 in H_2O, stationary bubble, 10° C. (from data of Higbie) calculated by Danckwerts (4)

4×10^{-6}	4×10^{-6}

It is significant that the experimental values, calculated on the basis of the small deviations from Equation (6), are even of the same order of magnitude as Baron's theoretical predictions. It is worthy of mention that the accommodation coefficients for pure substances range from 0.01 to 1, indicating a much higher efficiency of transfer than for unlike substances. The variation of accommodation coefficient with Reynolds number implies an effect of the concentration, or age, of the liquid surface. At low Reynolds numbers, the agreement between experimental and theoretical values is very good.

Previous investigators have suggested that the reduction in mass transfer upon the addition of wetting agent is due to the hindrance of the diffusing molecules by the large organic molecules concentrated at the surface instead of to the elimination of rippling. The close agreement between Peaceman's data without wetting agent in short columns and those of the authors with wetting agent in a long column casts doubt upon this contention.

In order to examine more directly the role of wetting agent as a resistance to diffusion, carbon dioxide absorption runs were made in a 1.524-in.-long column, similar in design to those of Peaceman, with and without wetting agent. Since rippling does not exist in either case, a comparison of the absorption results should show whether or not the wetting agent causes a resistance to mass transfer. The results are presented in Table 2.

These data indicate an 11% decrease in absorption rate due to the presence of wetting agent. It is apparent, then, that the elimination of rippling is responsible for most of the 150% decrease in mass transfer that results when wetting agent is added in a long wetted-wall column. In fact, it is possible that the 11% decrease observed in the short column is actually due to the elimination of minor disturbances at the liquid outlet; in this case data taken with wetting agent present would be more representative of the true rate of mass transfer into a laminar film than those taken without.

It is apparent that consideration of interfacial resistance may be an important factor in the design of mass-transfer equipment, particularly in instances in which the liquid- and gas-side diffusional resistances are small. Failure to account for interfacial resistance resulted in about a 30% error in the worst case tested experimentally, but it is conceivable that it could be of more importance in other situations, such as the dispersion of gas bubbles in liquids or of liquid droplets in gases.

Table 2.—Comparison of Absorption Rates With and Without Wetting Agent in 1.524-in. Column

Temperature = 25° C.,

Liquid Reynolds number = 418

k_L' (theor.)	k_L (no wetting agent)	k_L (with wetting agent)
1.71	1.41	1.28
1.71	1.47	1.27
1.71	1.51	1.23
		1.44
---	---	---
avg. = 1.71	1.47	1.31
	(a = 7.9 × 10⁻⁶)	(a = 4.2 × 10⁻⁶)

Mass-Transfer Results With Rippling

Experimental determinations were also made on the absorption and desorption of oxygen and of carbon dioxide with no wetting agent added to prevent rippling. The results are presented in Figures 6 and 7 and show, as expected, that the rate of mass transfer is up to 250% of that predicted by Equation (6) and observed when ripples are absent. This increased rate is probably caused by a combination of two effects, (1) the bulk mixing caused by the ripples and (2) the increase in the surface area.

TRANSITION TO TURBULENCE

From Figures 6 and 7, it may be seen that the slopes of the lines undergo a sharp decrease at a Reynolds number of about 1,200. At the same Reynolds number, visual observations of a falling film containing wetting agent indicate a definite transition in the character of the flow. In fact, the mixing in the film was sufficiently violent to produce foaming at the surface of the film because of the presence of wetting agent. In runs without wetting agent, the difference in flow was also visually discernible, but the transition was somewhat obscured by the presence of ripples. From these considerations, it is concluded that a transition to turbulence occurs at a Reynolds number of about 1,200. This is in agreement with the theoretical and experimental evidence of Dukler (5) and with the data of Schoklitsh (17) and of Fallah, Hunter, and Nash (6).

DIFFERENCE BETWEEN ABSORPTION AND DESORPTION

Probably the most striking feature of the data taken with ripples present is that the transfer resistance for absorption is different from that for desorption, both for oxygen and for carbon dioxide. In the case of oxygen, the rate of desorption is higher than the rate of absorption, but for carbon dioxide, the opposite is true. This is contrary to the results of two previous investigators

Fig. 5. Generalized Liquid-Side Mass-Transfer Correlation for Falling Liquid Films.

who have made comparisons for cases in which the liquid-side resistance is controlling. Carlson (3) found that the rates of absorption and of desorption were the same for oxygen and for carbon dioxide in water in a stirred flask, and Allen (18) found that they were the same for carbon dioxide in a packed tower. Also, simple diffusion theory predicts them to be the same.

Since all efforts to locate experimental causes for the difference failed, it is necessary to consider the possibility of an actual difference. The data of the two previous investigators who compared absorption and desorption are not extensive, and neither was conducted in a wetted-wall column. Perhaps it is significant that in Carlson's experiments, conducted in a stirred flask, and in Allen's, in a packed tower, the liquid was mixed internally to a much greater degree than in the authors' wetted-wall experiments.

In an effort to explain the difference in rates as an actual one, the possibility of chemical reaction was considered. However, the solution of the differential equation for absorption and simultaneous, pseudo-first-order, reversible reaction is no different from that for desorption and simultaneous reaction, at least for short times of contact. The possible reactions that could occur here are of that type.

A second possible explanation is that the accommodation coefficients could be different for the two directions. This would be expected to manifest itself to a greater extent at high transfer rates and therefore would cause a smaller difference at high Reynolds numbers or when rippling is absent. These effects accord with the experimental results. It

is also possible that the effect could result from variation of the accommodation coefficient with concentration. This is suggested by the fact that experimentally observed accommodation coefficients increase with increasing Reynolds number.

Summary

The experiments conducted without rippling lend strong support to the validity of Equation (6) and suggest that the small difference between experimental results and theoretical predictions may be due to lack of thermodynamic equilibrium at the interface.

Experiments conducted with rippling present show, as expected, mass-transfer rates severalfold higher than those predicted for the absence of rippling.

The transition from laminar to turbulent flow occurs at a Reynolds number of about 1,200, in agreement with the findings of previous investigators.

Notation

A_1 = average inlet concentration, lb. moles/cu. ft.

A_2 = average outlet concentration, lb. moles/cu. ft.

A_G = concentration of A in gas, lb. moles/cu. ft.

A_G^* = fictitious gaseous concentration of A that would be in equilibrium with A_1, lb. moles/cu. ft.

A_i = liquid concentration of A at the interface, lb. moles/cu. ft.
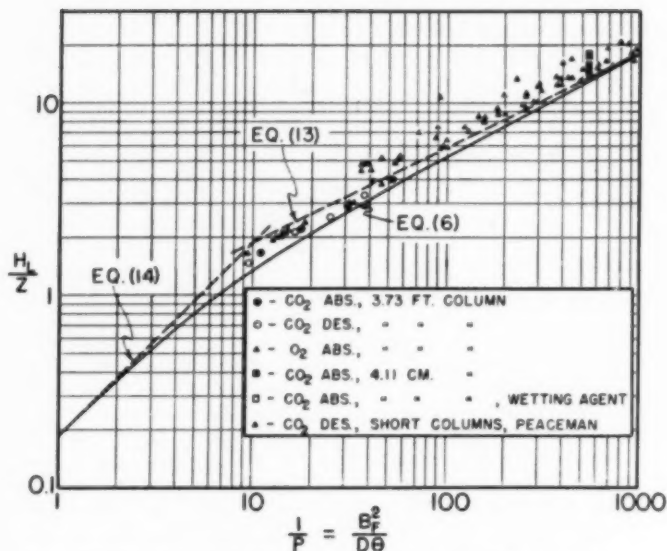
Fig. 6. Absorption and desorption of oxygen without wetting agent, 3.73-ft. column, 0.99 in. I.D., 25° C.
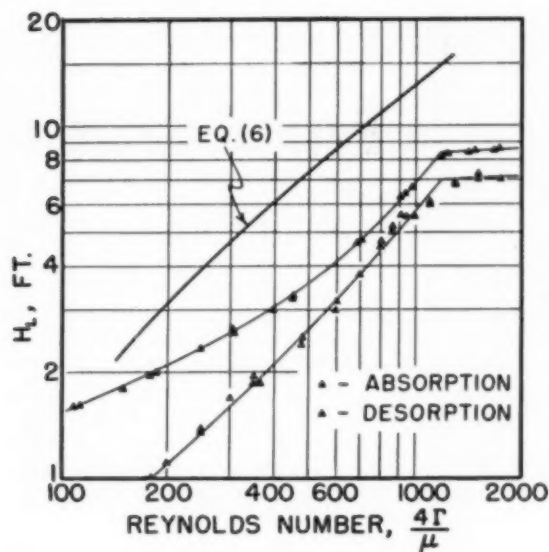
▲ – ABSORPTION
▲ – DESORPTION
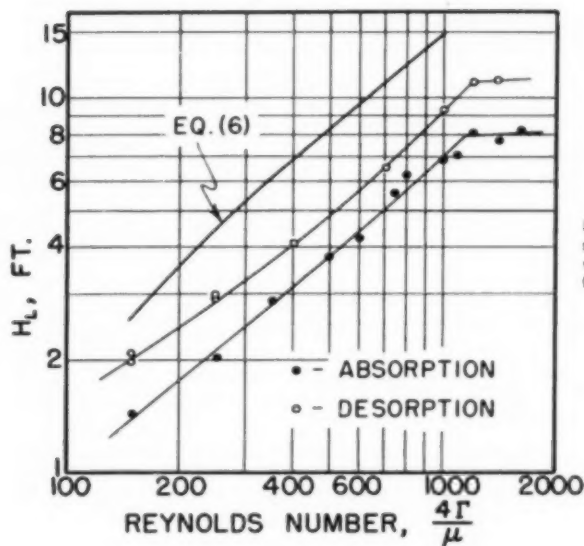
Fig. 7. Absorption and desorption of carbon dioxide without wetting agent, 3.73-ft. column, 0.99 in. I.D., 25° C.

● – ABSORPTION
○ – DESORPTION

x_F = thickness of fictitious stagnant film of Whitman film theory, ft.

z = length of wetted surface, ft.

a = accommodation coefficient

a_l = accommodation coefficient for transfer into liquid

a_c = accommodation coefficient for transfer into gas

Γ = mass velocity of liquid layer, lb./(hr.)(ft. of wetted perimeter)

μ = liquid viscosity, lb./(hr.)(ft.)

ρ = liquid density, lb./cu. ft.

θ = time of contact of gas-liquid interface, hr.

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$A_i°$ = fictitious liquid concentration of A that would be in equilibrium with the true gas concentration A_{Gi}, lb. moles/cu. ft.

A_o = initial concentration of A in the bulk of the liquid, lb. moles/cu.ft.

B_F = actual film thickness, ft.

D_A = diffusion coefficient of A in the liquid, sq. ft./hr.

g = local acceleration of gravity, ft./hr.^{2}

H = Henry's law constant, (lb. moles/cu.ft. in gas/lb. mole/cu.ft. in liquid).

H_L = height of a liquid-film transfer unit based on a logarithmic-mean driving force, ft.

k_L = mass-transfer coefficient for interfacial resistance, ft./hr.

k_L = apparent liquid-film coefficient, ft./hr.

k_L' = true liquid-film coefficient, exclusive of interfacial resistance, ft./hr.

$(k_L)_{l. m.}$ = apparent liquid-film coefficient based on logarithmic-mean driving force, ft./hr.

M = pound moles of gas striking liquid surface, lb. moles/(sq. ft.)(hr.)

M_l = pound moles of gas entering liquid surface, lb. moles/(sq.ft.)(hr.)

M_G = pound moles of gas leaving liquid surface, lb. moles/(sq. ft.)(hr.)

N_A = mass-transfer rate, lb. moles/(hr.)(sq. ft.)

p = $D_A \theta / B^2_F$, dimensionless parameter

u_{avg} = average linear velocity of falling film, ft./hr.

u_s = surface velocity of falling film, ft./hr.

$\bar{u}$ = root-mean-square velocity of gas molecules, ft./hr.

x = space coordinate into the liquid layer, ft.

A Correlation of Flooding Velocities in Packed Columns

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Experiments have proved that for countercurrent mulitphase columns the degree of dispersion and turbulence is increased by operating at high volumetric rates in the column. The maximum or limiting rate is called the "flooding point" above which one phase is partially prevented from passing through the column and begins to be ejected back out with the other phase. Since rates approaching flooding are desirable from a maximum extraction standpoint, it is important to know the limiting or flooding points for a given set of conditions.

It is one purpose of this paper to investigate the influence on the flooding rates of liquid-liquid systems in packed columns of such pertinent physical properties as the densities and viscosities of the two phases, the density difference, and the interfacial tension, as well as the size of the material used to pack the column.

A field closely allied to liquid-liquid extraction is gas absorption or desorption. Here too the problem of a limiting or flooding velocity exists. Considerable data have been published on the flooding points of gas-liquid systems in packed columns. Therefore, a second purpose of this study is to attempt to correlate the existing data on the flooding of gas-liquid systems with that obtained in this research and in preceding ones on liquid-liquid systems.

Previous Work

LIQUID-LIQUID SYSTEMS

Much of the early work on flooding in liquid-liquid packed columns was done incidental to other investigations and the data obtained were meager and not too reliable. In this category are the reports of Rushton (15), Appel and Elgin (2), Sherwood, Evans, and Longcor (18), and Row, Koffolt, and Withrow (14).

Blanding and Elgin (6) described their investigations of the design and operations of spray and packed columns, pointing out the importance of the proper design of the entrance and distributor. Breckenfeld and Wilke (7)

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Flooding points have been determined in a 6-in. diam. liquid-liquid extraction column packed with ½-in., ¾-in. and 1-in. Raschig rings. Physical properties of both liquids were varied over a wide range in the 226 runs made.

The flooding velocities reported here and elsewhere on liquid-liquid and also on gas-liquid systems are brought together by a new, dimensionally consistent correlation to within a mean deviation from the calculated flooding velocity of 10.2%. Furthermore, it has been found that previous correlations are lacking in some respects, and may lead to errors in the order of two or three-fold in certain ranges of physical properties of the fluids.

The terms *dispersed phase* and *continuous phase* are ambiguous as conventionally used in connection with packed columns. To avoid unnecessary confusion, that phase which enters the column at the end opposite from the interface is called the opposite phase and that which enters adjacent to the interface, the adjacent phase.

Visual observations of the flow behavior of the various liquids are discussed in some detail. Flooding is characterized by the appearance of a layer of the opposite phase at the far end of the column from the interface. The appearance of the column prior to flooding is different, depending upon which phase is adjacent and which is opposite, but this has no effect on the magnitude of the flooding point.

studied flooding in a 2.6-in. column, using a gasoline-water system with various amounts of butyl alcohol added to change the interfacial tension. Other liquids used were methyl isobutyl ketone, glycerol solutions, carbon tetrachloride, and toluene.

Ballard and Piret (4) investigated the flow mechanisms of countercurrent liquid-liquid extraction in a 2.03-in. and a 3.75-in. column. They were able to correlate what they described as transition points representing sudden changes in the mechanism of flow. However, they were unable to correlate their data on ¼-in. porcelain Raschig rings in the smaller column with the rest of their data.

For their investigations, Crawford and Wilke (8) used a 12-in. column, which, to date, is the largest reported in the literature that has been used for flooding-point determinations. The packings used were ½-in., 1-in. and 1½-in. carbon Raschig rings. Various systems were used to obtain a wide range in physical properties.

The most recent data are those of Dell and Pratt (9). They used both a 3-in. and 6-in. diam. column and a wide variety of packings and chemicals. Their data constitute the most complete investigation of liquid-liquid flooding heretofore reported.

GAS-LIQUID SYSTEMS

The subject of flooding in gas-liquid packed columns received earlier attention than did the allied field of liquid-liquid flooding. White (22), Uchida and Fujita (20), Sherwood, Shipley and Holloway (19), Elgin and Weiss (4), Sarchet (16), Schoenborn and Dougherty (17), and Bain and Hougen (3) contributed to the fund of gas-liquid flooding data which is available in the literature. Generalized correlations were developed by Sherwood, Shipley, and Holloway (19) and by Bertetti (5). A critical study of these correlations was made by Lobo, Friend, Hashmall, and Zenz (13), who noted that neither adequately represented subsequent data. They attributed the deviations to variations in a/F^3 data for different packings. By assigning arbitrary values of a/F^3 to the various packings they were able to improve greatly Sherwood's correlation. They investigated the packing characteristics of different-sized Raschig rings and Berl saddles and found that the method of packing a column affected the re-

sultant a/F^3 data. A correlation, similar to Bertetti's, was recently proposed by Dell and Pratt (10).

New Definitions

The terms dispersed and continuous have definite meanings to the engineer based upon his long usage of them in different fields. In the operation of an extraction column, especially at high rates, it is often difficult to tell which phase is dispersed and which is continuous. This is particularly true in packed columns where one phase may wet the packing preferentially. This phase never bubbles through the packing but slides over it in a film even when it is supposedly dispersed. At high rates, where the holdup of the dispersed phase is great, the so-called continuous phase may actually bubble through the dispersed phase. To avoid this unnecessary confusion in definition it is proposed to call that phase which enters the column at the opposite end from the interface the opposite phase, and that which enters adjacent to the interface, the adjacent phase.

Experimental Work

APPARATUS

The apparatus used in this study followed in principle that recommended by Blanding and Elgin (6) and is shown in Figure 1. The main section of the column was 6-in. I.D. and 72 in. long. It was made of Pyrex glass and each end was flanged. Separate end sections were used for both top and bottom. The opposite phase always entered the column through 28, ¼-in. nozzles, 1-in. long, uniformly distributed across a ⅛-in. brass disk which served as the nozzle support. When the opposite phase had the lighter density the nozzles were at the bottom of the column and the brass disk also served as the packing support. Thus the nozzles projected up into the packing.

An enlarged conical Pyrex-glass section whose maximum diameter was 8½ in. enclosed the nozzles and their support. Above the column was an extra section 6 in. in diam. and 12 in high. The interface between the two phases was maintained in this section throughout these runs. The adjacent phase was introduced down into the column through two ¾-in. tubes which projected below the interface. Pressure taps leading to a common manometer were located at both the top and bottom of the column. The upper pressure tap extended below the interface so that the lines leading from the tap to the manometers were both always filled with the adjacent phase.

For those runs in which the heavy phase was the opposite one the conical section containing the nozzles was at the top of the column. In this case a cylindrical brass section 8½ in. in diam. and 12 in. long was used for the bottom section. The adjacent phase entered through two ¾-in. tubes which extended up 9 in. into the column. The interface in these series of runs was always held below the entrance of the adjacent phase
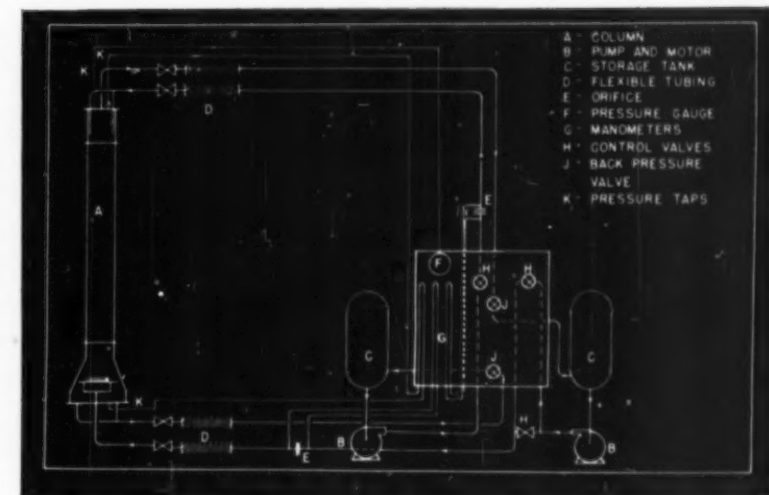
and about 6 in. above the bottom of the column. A sight-glass was used to locate the interface. A brass weir caused the adjacent phase to change direction and to enter the column more uniformly. The packing rested on the bottom of this brass cylindrical section and the effective packing height above the entrance of the light phase was maintained the same for both types of operation, about 72 in.

All fittings, connections, and the ¾-in. pipes were made of copper or brass to minimize corrosion. All gaskets in the column were made of Teflon envelopes with neoprene rubber inserts for resiliency. These were completely resistant to all the liquids used and showed not the slightest wear. The various glass sections were bolted together using aluminum flanges and eight steel bolts per section. Each bolt was tightened with a tension wrench to a torque of 30-in. lb. so as to prevent any undue strain on the glass.

A set of seven different calibrated orifice plates was used in each line to cover a full range of flow. Cold water was circulated through a jacket around the pipe leaving the pumps. This helped in keeping the liquids close to room temperature for all the runs. Needle valves between the pumps and orifices were used to control the rates. Where high rates were desired a by-pass gate valve was used instead of the needle valve. Back-pressure valves located between the exit from the column and the storage tanks were used to control the location of the interface in the column. In this manner the system was essentially closed and the problem of evaporation, causing a change in either phase composition, was eliminated. This method of controlling the position of the interface was effective and is recommended as being superior to the customary variable inverted U-tube.

Storage tanks for each fluid were made of stainless steel and held approximately 10 gal. The holdup in the column itself was about 11 gal. The total inventory of each phase was also about 11 gal.

The whole column, including piping, was 9 ft. high and stood some 10 ft. above the floor. The column was supported between two vertical up-

rights of 1-in. pipe made rigid by welded ¾-in. braces. The top of each upright was fastened to a ceiling beam by means of large pins. The bottom of each upright was hinged to the concrete floor. An overhead pulley mechanism allowed the whole column, supporting uprights and all, to be gently lowered to the floor while it was being held by the hinges at the lower end. In this manner the bottom section could then be removed with no undue strain on the glass and the packing replaced, or the column inverted.

PACKING

Three different sizes of porcelain Raschig rings were used as the packing. These are the nominal ½-in., ¾-in., and 1-in. rings manufactured by the United States Stoneware Co. The aqueous phase preferentially wets this type of packing. The column was filled with water and the rings were dropped in from the top several at a time. This encouraged random packing. The surface area per unit of column volume, a, and the fractional void volume, F, were determined for each packing. The average area and volume of an individual ring were calculated from the average dimensions of the rings. The number of rings required to fill the known volume of the column was found by actually counting the individual rings. From these data the values of a and F could be calculated. The column was packed twice with each type of packing, once originally and a second time when the column was reversed. The values of a and F differed slightly as shown in Table 1.

Table 1.—Values of a and F for the Various Packings

Conical Section at the Top

Ring size, in.	½	¾	1
a, sq.ft./cu.ft.	101	62.5	49.7
F	0.595	0.722	0.773

Conical Section at the Bottom

Ring size, in.	½	¾	1
a, sq.ft./cu.ft.	98.3	60.3	50.6
F	0.602	0.732	0.769

Fig. 1.

A - COLUMN
B - PUMP AND MOTOR
C - STORAGE TANK
D - FLEXIBLE TUBING
E - ORIFICE
F - PRESSURE GAUGE
G - MANOMETERS
H - CONTROL VALVES
J - BACK PRESSURE VALVE
K - PRESSURE TAPS

LIQUIDS

Water was used as the aqueous phase for all series of runs except those in which sugar solutions were used. Various liquids were used as the nonaqueous phase. A medium boiling petroleum fraction was used for many of the runs. At 20° C. its density is 0.80 g./cc. and its viscosity 0.95 centipoise. Blends of this solvent and carbon tetrachloride were used to obtain densities between 0.80 and 1.52 g./cc. without appreciably changing the viscosity or interfacial tension. Methyl ethyl ketone was added to the petroleum solvent to lower the interfacial tension with water. This ketone is slightly soluble in water causing an increase in its viscosity and a decrease in its surface tension. High viscosities were obtained in the solvent phase by using a heavy grade of mineral oil. This enabled the solvent viscosity to be varied over greater than a 100-fold range.

The following data were determined for each liquid in a series: density, viscosity, interfacial and surface tensions. The temperature of each liquid was also noted for each run and usually it was within a few degrees of the mean temperature of 20° C. It was found that although the various physical properties changed from run to run the amount of variation within a series was so slight that average values could be used in the final correlation for the sake of simplicity.

Hydrometers were used to determine the densities of each phase within an accuracy of 0.1%. Modified Ostwald viscosimeters were used to obtain the viscosities (1). The interfacial and surface tensions were calculated by the use of a modified drop-weight method described by Weissberger (21).

Physical properties of the fluids used in these tests for each series and other pertinent data are given in Table 2.

PROCEDURE

In most of the tests one phase velocity was held constant while the other one was gradually increased until flooding occurred. The first series of runs indicated that it made little difference on the final flooding velocity which phase was held constant.

The adjacent phase was pumped into the column until the latter was three fourths filled. Then the opposite phase was pumped in until the column was filled. With both phases flowing at low rates the interface was adjusted to the proper position in the column by means of the back pressure valves. Then one phase velocity was raised to the rate at which it was to be held for the rest of the run. Pressure taps at the top and bottom of the column measured the pressure drop across the column. The other phase velocity was held constant for from five to ten minutes until the pressure-drop readings remained constant. Then a small increase of approximately 10% of the manometer reading was made in this velocity. This was usually accompanied by a slight adjustment in one or both of the back pressure valves to maintain the interface at the desired location. The pressure drop increased as a result of the increased velocity and the increased holdup of the opposite phase. When the column again reached steady state as shown by the constancy of the pressure-drop-manometer reading another increase in the velocity was made. This cyclic process was repeated until the flooding took place.

The Final Correlation

Physical properties of the fluids and packing which directly influenced the flooding velocities as determined in this investigation have been combined in the form of completely dimensionless groups in the final correlation. Figure 2 represents the correlation of these original data. The ordinate contains modified Reynolds numbers and Froude numbers for the two phases plus several dimensionless ratios required to bring in the necessary variables. These dimensionless groups are:

$$\left(\frac{u_w^2 a}{g}\right)^{0.55} \left(\frac{u_s^2 a}{g}\right)^{-0.06} \left(\frac{\rho_s}{\rho_w}\right)^{0.30}$$

$$\left(\frac{\Delta\rho}{\rho_w}\right)^{-0.50} \left(\frac{u_w \rho_w}{\mu_w a}\right)^{-0.10} \left(\frac{u_s \rho_s}{\mu_s a}\right)^{-0.08}$$

$$\left(\frac{\sigma_{w-s}}{\sigma_{w-a}}\right)^{0.50} F^{0.805}$$

Multiplication of these terms simplifies the ordinate to:

$$\frac{u_w \rho_w^{0.10} \rho_s^{0.22} \mu_w^{0.10} \mu_s^{0.08}}{u_s^{0.20} \Delta\rho^{0.50}} \left(\frac{\sigma_{w-s}}{\sigma_{w-a}}\right)^{0.50}$$

$$\left(\frac{a}{F^{1.2}}\right)^{0.67}$$

and, in order to use the unit-wise inconsistent terms described in the notation, this final term must be multiplied by 3.33×10^{-5}.

In design calculations—that is the principal use for a correlation of this type—the volumetric flow rates are known from other considerations besides flooding. Thus, although the superficial linear flow rates through the column are not known until the diameter is determined, the ratio of the superficial linear velocities is known. This ratio by itself, u_s/u_w, is used as the abscissa in this correlation.

The 226 flooding point determinations of this investigation are correlated in Figure 2 within a mean deviation of the experimental flooding point from the calculated velocity of 13.3%.

The dimensionless ratio $(\sigma_{w-s}/\sigma_{w-a})^{0.50}$ is used in the correlation to represent the effect of the interfacial tension between the two fluids. This term has values of less than one for liquid-liquid systems, ranging from 0.45 for a toluene-methyl ethyl ketone-water system to 0.81 for a carbon tetrachloride-petroleum ether-water system. It reduces to unity for gas-liquid systems where the interfacial tension between the two phases is the surface tension of the liquid. This is in line with the reported results of Sherwood, Shipley, and Holloway (19) that variations in surface tension had no influence on the flooding point of gas-liquid systems. However, examination of the liquid-liquid flooding data in the literature showed that only one other investigator (4) reported both interfacial and surface-tension data. Therefore, in order to apply this correlation to other liquid-liquid flooding data the value of $(\sigma_{w-s}/\sigma_{w-a})^{0.50}$ had to be estimated from just the interfacial-tension data reported in the various investigations. Figure 3 shows the experimental relationship between σ_{w-s} and $(\sigma_{w-s}/\sigma_{w-a})^{0.50}$ used for this estimation.

All the flooding velocity data on random packed Raschig rings and Berl
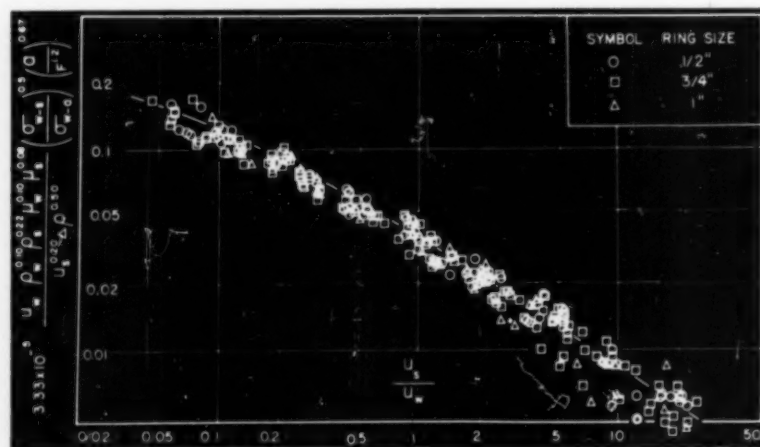
Fig. 2. Correlation of original data.

Table 2.—Summary of Pertinent Data for Each Series

Series	Run Nos.	Adjacent Phase	Opposite Phase	Water Dens. g./cc.	Solv. Dens. g./cc.	Water Visc. centipoise	Solv. Visc. centipoise	Int. Tens. $w-s$ dynes/cm	Surf. Tens. $w-a$ dynes/cm
				¾-in. Raschig Rings					
1	1-17	petroleum solvent	water	1.00	0.80	1.00	0.95	46	71
2	18-30	pet. solv. + CCl₄	water	1.00	0.88	1.07	0.98	42	71
3	31-39	pet. solv. + CCl₄	water	1.00	0.925	1.05	1.00	41	71
4	40-46	pet. solv. + MEK	water	1.00	0.812	1.08	0.90	25.5	54
5	47-50	pet. solv. + MEK	water	0.998	0.80	1.10	0.88	21.5	47
6	51-55	pet. solv. + MEK	water	0.995	0.81	1.12	0.85	17.6	44.5
7	56-62	pet. solv. + MEK	water	0.989	0.80	1.32	0.80	11.8	38.5
8	63-70	Mineral Oil	water	1.00	0.86	1.00	113	43	71
9	71-76	Mineral Oil	sugar soln.	1.27	0.87	38.0	113	43	67
10	77-85	pet. solv. + CCl₄	sugar soln.	1.27	1.09	38.0	0.99	43	67
11	86-90	pet. solv. + CCl₄	sugar soln.	1.266	0.89	37.5	0.98	43	67
				Invert Column—¾-in. Raschig Rings					
12	91-98	CCl₄ + pet. solv.	water	1.00	1.07	1.00	1.00	40	70
13	99-106	CCl₄ + pet. solv.	water	1.00	1.52	1.00	1.00	43.4	71
14	107-114	CCl₄ + pet. solv.	water	1.00	1.31	1.00	1.00	43	71
15	115-119	water	pet. sol. + CCl₄	1.00	0.87	1.00	0.98	45.3	71
16	120-123	water	pet. sol. + MEK	0.990	0.80	1.07	0.88	20.7	47
17	124-127	water	min. oil + pet. sol.	1.00	0.86	1.00	70.0	43	71
				Invert Column—¾-in. Raschig Rings					
18	128-132	water	CCl₄ + pet. sol.	1.00	1.353	1.00	1.00	43	71
				½-in. Raschig Rings					
19	133-137	water	CCl₄ + pet. soln.	1.00	1.353	1.00	1.00	43	71
20	138-141	min. oil + pet. sol.	water	1.00	0.86	1.00	60	43	71
21	142-145	pet. sol. + MEK	water	1.00	0.824	1.00	0.92	26.7	56
22	146-150	pet. sol.	water	1.00	0.80	1.00	0.95	44.5	71
23	151-155	pet. sol.	sugar sol.	1.221	0.80	10.8	0.95	43	68
				Invert Column—½-in. Raschig Rings					
24	156-160	sugar sol.	pet. sol.	1.220	0.80	11.0	0.96	43	68
25	161-166	water	pet. sol.	1.00	0.80	1.00	0.95	43	71
26	167-171	water	pet. sol. + MEK	1.00	0.82	1.00	0.91	22.6	49
27	172-175	water	pet. sol. + min. oil	1.00	0.869	1.00	38	43	71
28	176-180	CCl₄ + pet. sol.	water	1.00	1.215	1.00	1.00	43	71
				1-in. Raschig Rings					
29	181-185	CCl₄ + pet. sol.	water	1.00	1.092	1.00	1.00	43	71
30	186-190	water	min. oil + pet. sol.	1.00	0.688	1.00	25	43	71
31	191-195	water	pet. sol. + MEK	0.998	0.816	1.05	0.92	23	48.5
32	196-200	water	pet. sol.	1.00	0.80	1.00	0.95	44	71
33	201-204	sugar sol.	pet. sol.	1.16	0.80	4.25	0.95	43	70
				Invert Column—1-in. Raschig Rings					
34	205-208	pet. sol.	sugar soln.	1.155	0.80	3.15	0.95	43	70
35	209-212	pet. sol.	water	1.00	0.80	1.00	0.95	44	71
36	213-217	min. oil + pet. sol.	water	1.00	0.865	1.00	7.3	43	71
37	218-221	pet. sol. + MEK	water	0.990	0.81	1.08	0.90	22.5	49
38	221-226	water	pet. sol. + CCl₄	1.00	1.076	1.00	1.00	40	71

saddles published in the literature for both gas-liquid * and liquid-liquid systems have been correlated in Figure 4. All in all, 1,024 test runs, representing the results of fifteen sets of investigations using forty-eight packings, have been tested by this correlation. The mean deviation of the experimental flooding velocities from those calculated from the correlation for all 1,024 points is 14.2%.

LIQUID-LIQUID SYSTEMS

A breakdown of the mean per cent deviation from the calculated flooding velocity for liquid-liquid systems is given in Table 3. The correlation is seen to be quite good even for the industrial size 1½-in. Raschig rings used by Crawford and Wilke (8) in their 12-in. column. The only bad deviations are the data of Ballard and Piret (4). No good explanation is available for this deviation with the possible exception that many of the data were obtained using a 2.03-in. column which is the smallest reported in the literature. However, the 2.6-in. column of Breckenfeld and Wilke (7) is not much larger and their data are much more closely correlated.

This correlation was completely developed when the data of Crawford and Wilke (8) became available in the literature. Since their 12-in. column is the largest used yet for flooding-point determinations, interest was aroused by their publication. Their flooding-velocity data have a mean deviation from the calculated values determined from Figure 4 of 13.2%.

Quite recently Dell and Pratt (9) reported the results of their extensive flooding-velocity tests. Their data cover a wide range of packing sizes and a variety of chemicals. For the 253 runs reported using Raschig rings and Berl saddles the mean deviation of the experimental flooding data from the calculated results of this correlation is 12.3%.

GAS-LIQUID SYSTEMS

Several correlations have been presented in the literature for gas-liquid data. Lobo, Friend, Hashmall, and Zenz (13) modified the correlation originally developed by Sherwood, Shipley, and Holloway (19) by assigning arbitrary values of a/F^3 to the various packings. Table 4 gives a breakdown of the mean per cent error in calculating the flooding velocity for their correlations and compares this with the present one. The

Fig. 3.

RELATIONSHIP BETWEEN $\sigma_{w\text{-}s}$ AND $\left(\dfrac{\sigma_{w\text{-}s}}{\sigma_{w\text{-}s}}\right)^{0.6}$
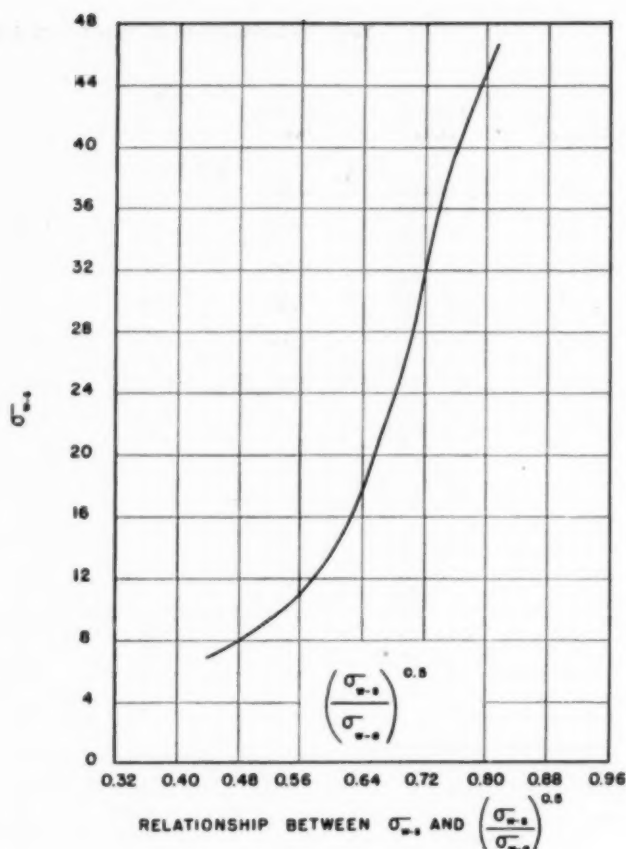
Table 3.—Accuracy of New Correlation for Liquid-Liquid Systems

Investigator	Packing Raschig Rings (in.)	Runs	Mean Per Cent Error in Flooding Velocity	
			Using Actual σ & F data	Using Arbitrary σ & F data
Hoffing and Lockhart	¾	132	11.3	12.2
	½	48	17.4	14.6
	1	46	12.3	13.4
Breckenfeld and Wilke	¼	58	18.5	6.3
	½†	5	20.1	5.4
Blanding and Elgin	½†	21	11.8	6.5
	½	11	11.0	15.8
Row, Koffolt, and Withrow	½	3	19.8	25.0
	½†	4	17.0	30.8
Crawford and Wilke	½	8	12.8	4.3
	1½	8	17.3	3.9
	1	29	11.7	4.4
Ballard and Piret	¼	37	60.0	100.0
	½	6	51.8	41.3
Dell & Pratt	¼	13	9.6	41.2
	¾	113	9.2	9.2
	½	23	13.0	3.7
	¾	40	17.9	13.8
	1	11	11.4	10.4
	¼†	16	7.8	11.8
	½†	26	40.0	15.4
	1†	11	8.3	8.3
Total number of points		669		
Over-all avg. % deviation in v_w			14.8	11.0
Over-all avg. % deviation in column diameter			7.1 to 7.7	5.4 to 5.7

† Berl Saddles

Table 4.—Comparison of New Correlation with Lobo, et al. (13) on Gas-Liquid Systems

Average Per Cent Error

Investigator	Packing Raschig Rings (in.)	Runs	Lobo, et al. Empirical	Lobo, et al. Experimental	Present Correlation Using Actual a & F data	Using Arbitrary a & F data
Bain and	½	29	9.4	3.6	21.8	7.2
Hougen	1	35	7.1	8.2	9.2	6.7
	1†	5	21.7	40.7	26.0	23.0
	1½†	4	24.3	24.3	34.5	10.6
Elgin and	⅝	7	20.8	26.0	30.0	19.8
Weiss	¼†	3	16.2	16.3	8.1	15.8
	½†	23	6.2	6.2	12.8	20.0
Laxton and	⅜	3	15.2	20.1	3.6	3.6
Huber-see	½	5	4.1	8.8	28.5	5.5
White (20)	¾	4	17.8	12.2	33.5	31.3
New-see	⅝	5	19.4	26.1	6.4	7.8
White (20)	¾	5	17.3	31.4	14.1	22.2
	1	3	14.7	22.2	7.2	15.0
	1¼	2	10.2	11.0	12.7	2.8
Rose and	⅜	1	....	....	6.6	12.6
Higby-see White (20)	⅝	2	....	....	5.3	3.6
Sarchet	½	4	9.2	25.1	11.6	14.5
	1	5	4.8	8.2	13.5	13.5
	1 (ribbed)	7	7.4	6.8	4.7	4.7
Schoenborn	¼	36	24.1(33 runs)	28.8(33 runs)	22.6	21.7
and	½	29	3.7	6.8	6.3	5.7
Dougherty	1	18	4.6	6.0	9.8	7.8
	1 (ribbed)	19	7.4	6.9	6.9	6.9
	½†	18	23.5	24.4	30.0	10.5
Sherwood, Shipley	½	77	6.8	5.2	13.0	10.1
and Holloway	0.6†	12	2.9	2.7	28.1	16.6
Uchida and	⅝	8	17.2	25.3	....	....
Fujita	1	13	16.6	21.9	....	....
	1¾	13	7.3	7.3	....	....
Total Number of points		391	....	....	....	....
Over-all avg. % Deviation in u_w			10.8	11.5	13.6	9.6
Over-all avg. % Deviation in tower diameter			5.1 to 5.5	5.3 to 6.0	6.6 to 7.1	4.7 to 4.9

† Berl saddles.

column under Lobo, et al. labled Empirical represents their correlation with the arbitrarily assigned a/F^2 values. They also determined their own values for a/F^2 experimentally and correlated the existing data with them. The column in Table 4 labeled Experimental represents these results.

In the development of the correlation presented in this paper the actual values of a and F, when measured by the investigators, were used. Several investigators, namely, Sarchet (16), Schoenborn and Dougherty (17) New, Laxton, and Huber, and Rose and Higby (22), did not measure a and F. In these cases the values of a and F which were measured by Lobo, et al. (12) were used. Two of the investigators used ribbed Raschig rings which had a greater surface area than the plain rings. However, the flooding velocities with these rings were similar to those when plain rings of the same nominal size were used. Therefore, the same values of a and F were used for both types of rings.

An examination of Table 4 shows that the present correlation, using the reported a and F, is slightly poorer than those of Lobo, et al. However, much of the deviation from the correlation is due to the packing factor $a/F^{1.2}$. For example, the data of Sherwood, Shipley, and Holloway for ½-in. Raschig rings closely parallel the curve but average some 10% below it. Figure 5 shows this graphically. These investigators used a wide variety of chemicals in their study and the narrowness of the band of their data in Figure 5 attests to the soundness of the correlation insofar as the physical properties of the two phases are concerned. Apparently, if, as Lobo, et al. did, arbitrary values for a and F were assigned to the various packings, the correlation would be improved. If the values for $(a/F^{1.2})^{0.67}$ which are shown in Table 5 are used in place of the actual values reported by the investigators, the over-all mean per cent deviation in u_w, the flooding velocity, is reduced to 9.6%, which is slightly superior to Lobo's correlation. A breakdown of this deviation is given in Table 4 also. When this correction

is applied to the liquid-liquid flooding data in Table 3, the mean deviation is reduced to 11.0%. The mean deviation from the calculated flooding velocity for all 1,024 runs for both gas-liquid and liquid-liquid systems is only 10.2%

The use of arbitrary packing factors for the various packings is justified since it appears that the least reliable data reported by the various investigators are their values of a and F. Small changes in the $a/F^{1.2}$ term cause relatively large changes in the calculated flooding velocity. Since different investigators have reported large differences in a and F for the same packings without correspondingly large differences in flooding velocity, the conclusion must be reached that either the a and F data are inaccurate or the packing factor term used in the correlation is incorrect or both. In either case it is simpler and, the data show, more accurate to use the arbitrary values given in Table 5 than to use the varying actual values.

Ballard and Piret (4) noticed a considerable difference between the appearance of the column prior to and including flooding—when the aqueous phase was made adjacent—compared to when it was the opposite phase. They also said that the actual flooding point is higher for the wetting phase opposite than for it adjacent. Blanding and Elgin (6) made a similar observation. Although it is true that the appearance of the column was markedly different at rates below flooding depending upon which phase is opposite, no such difference was observed in the magnitude of the flooding points.

Data of Blanding and Elgin for their ½-in. Berl saddles and ½-in. Raschig rings are plotted in Figure 6. The systems of naphtha-water and methyl isobutyl ketone-water were used. Data all follow the correlation with a minimum of scattering and it is difficult to detect which phase is opposite. In view of this evidence and that noted in this investigation it is apparent no significance need be attached to which phase is opposite and which adjacent in a correlation of flooding velocities.

Testing of Previous Correlations with New Data

In the previous sections it was shown that the correlation presented in this paper satisfactorily represents all the existing data on the flooding points of packed towers containing random packed Raschig rings and Berl saddles. It is of interest to show how correlations presented previous to this one represent the new data and if by any chance a correlation already exists which ties together liquid-liquid and gas-liquid data.

THE FINAL CORRELATION

Fig.

RECOMMENDED POINTS

ORDINATE	ABSCISSA
0.33	0.01
0.24	0.02
0.165	0.05
0.125	0.1
0.09	0.2
0.06	0.5
0.04	1
0.026	2
0.015	5
0.0092	10
0.0055	20
0.0031	50
0.0019	100
0.0012	200
0.00056	500
0.00033	1000
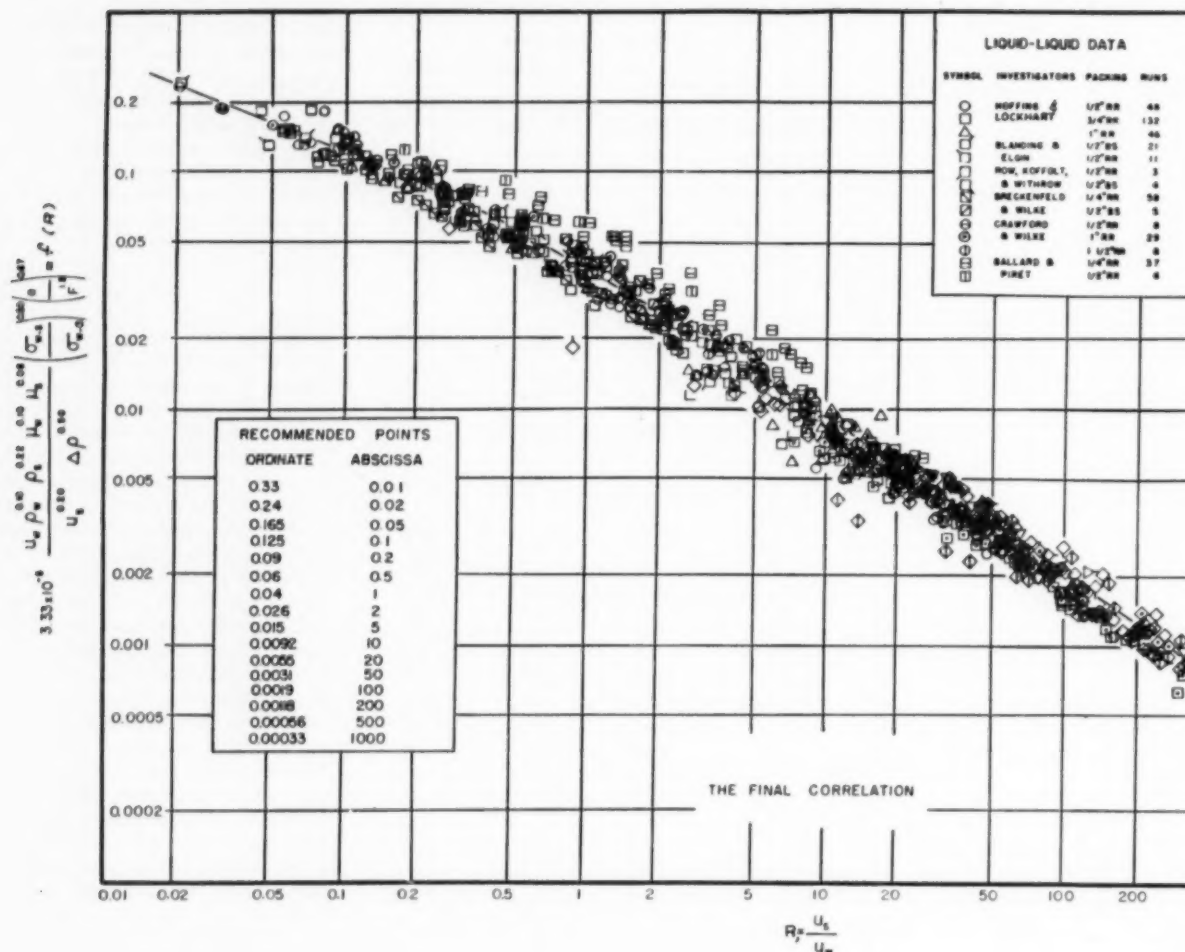
Breckenfeld and Wilke (7) made the first attempt at a general correlation of liquid-liquid flooding data. However, Crawford and Wilke (8) recently showed that their correlation was good for gasoline-water systems but was in serious error for high-viscosity and density-difference systems. Consequently, the latter pair proposed a correlation which they claim represents their own data and those of Blanding and Elgin (6) and Breckenfeld and

Wilke within 6.3%. The 226 runs of the present investigation were tested with this correlation with rather poor results. The mean deviation was 27%. One major fault is that their correlation fails to take into account the effect of the physical properties of the opposite phase. When the liquids used had properties considerably different from water or gasoline serious errors resulted. For example, for those runs in which a viscous sugar solution or mineral oil was used, the deviations were about 40%. Also, their correlation does not appear to represent the effects of density difference properly. Many of those runs where the density difference was very small, less than 0.1 g./cc., had deviations of more than 75%.

Spot checks on some of the gas-liquid data showed that Crawford and Wilke's correlation could not be used to predict the flooding points of these systems. The deviations were too excessive, being in the order of ten-fold.

Dell and Pratt (9) developed a corre-

lation that represents their own data within a mean deviation of 10%. This compares with the 11.3% mean deviation of their data with the corrected correlation of this paper. However, their correlation is somewhat poorer in representing the data of this and other investigations. The over-all mean deviation is more than 14% vs. the 11% mean deviation for the present correlation. Their correlation ignores the effect of the viscosity of the two phases on the flooding point which leads to serious errors for those runs where either phase had a high viscosity.

Their correlation, designed for liquid-liquid systems, is not directly applicable to gas-liquid systems. In a more recent article (10) they modified it somewhat and proposed it for the calculation of flooding velocities in gas-liquid systems. They claim good results were obtained in the correlation of Bain and Hougen's data but had difficulty representing the high-viscosity data of Schoenborn and Dougherty. No such difficulty was

Table 5.—Arbitrarily Assigned Values of $(a/f^{1.3})^{0.07}$ for Various Packings to Be Used in the Correlation

Nominal Size in.	Type of Packing	
	Raschig Rings	Berl Saddles
¼	67.0	62.0
⅜	35.2	
½	30.5	27.3
⅝	27.3	
¾	22.3	
1	18.2	19.0
1¼	17.5	
1½	16.9	12.6

GAS-LIQUID DATA

SYMBOL	INVESTIGATORS	PACKING	RUNS
	SHERWOOD, SHIPLEY, & HOLLOWAY	1/2" RR	83
		0.6" BS	12
	SARCHET	1/2" RR	9
		1" RR	7
	SCHOENBORN, & DOUGHERTY	1" RR	19
		1" RR	16
		1/2" BS	29
		1/4" RR	18
		1/2" RR	30
	LAXTON & HUBER	3/8" RR	3
		1/2" RR	5
		5/8" RR	4
	NEW	5/8" RR	6
		3/4" RR	9
		1" RR	5
	ROSE & HISBY	3/8" RR	1
		5/8" RR	6
	ELGIN & WEISS	1/2" BS	13
		5/8" BS	7
		1/4" BS	3
	BAIN & HOUGEN	1/2" RR	31
		1" RR	4
		1" BS	9
		1 1/2" BS	4
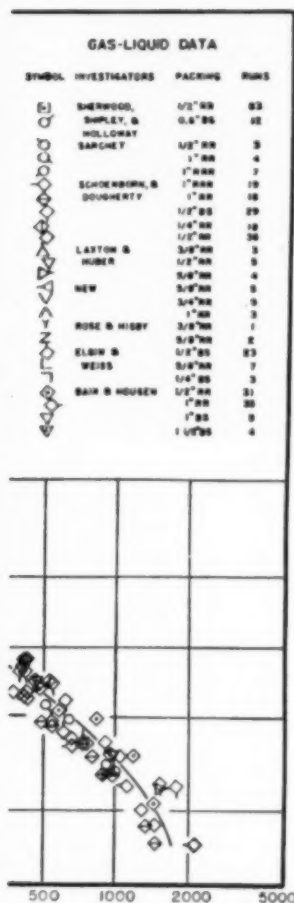
4.

noted using the present correlation. They didn't report a breakdown of their method on the existing data so no direct comparison of the two correlations is made here.

The correlation of Lobo, *et al.* for gas-liquid systems is quite good and the one presented here is only a slight improvement. However, Lobo's correlation is inapplicable for liquid-liquid systems. Several sample calculations showed the flooding points predicted from Lobo's correlation to be off by about a three-fold factor for liquid-liquid systems.

Thus, although Lobo's correlation is satisfactory for gas-liquid systems, it fails for liquid-liquid systems; whereas the correlation presented in this paper is slightly better than Lobo's for gas-liquid systems and at the same time correlates liquid-liquid systems with excellent accuracy.

Use of Correlation for Design Purposes

The correlation shown in Figure 4

can be arranged in a simplified form so as to obtain a direct solution for u_w. If R is the volumetric flow ratio, u_s/u_w, then u_w may be calculated from

$$u_w = \left[\frac{f(R)\Delta\rho^{0.50}}{3.33 \times 10^{-5}\rho_s^{0.22}\rho_w^{0.10}\mu_s^{0.08}\mu_w^{0.10}\left(\frac{\sigma_{w-s}}{\sigma_{w-a}}\right)^{0.5}\left(\frac{a}{F^{1.2}}\right)^{0.67}} \right]^{1.25} R^{0.25}$$

$f(R)$ is obtained from Figure 4, $(\sigma_{w-s}/\sigma_{w-a})^{0.5}$ from Figure 3, and $(a/F^{1.2})^{0.67}$ from Table 5. When the correlation is applied to gas-liquid flooding subscript w refers to the liquid phase and s to the gas or air phase. It must be remembered that all of the liquid-liquid data in the literature used to develop this correlation had the aqueous phase preferentially wetting the packing. Caution should be observed in applying the correlation to conditions where the aqueous phase does not preferentially wet the packing.

Visual Observations and Comments On Flow Behavior

The main advantage of having the extraction column made of glass is that the flow mechanism could be seen. Careful observations were made throughout the long series of tests.

WATER AS THE OPPOSITE PHASE

When the aqueous phase was opposite, both phases appeared to be continuous at rates considerably below flooding. The water slid down (or up depending upon the relative densities of the two phases) over the packing as a continuous phase. The solvent which was the adjacent phase in this case was, therefore, also continuous. Under these conditions the column was quiescent. The two phases slid by each other with a gently swaying appearance. As the rate of either phase was increased the water holdup increased in the column and isolated layers of water appeared. The solvent was forced to bubble up through these layers and in these places became discontinuous. This bubbling of the solvent indicated an approach to flooding and for all series where the solvent was adjacent, with the exception of those containing large percentages of carbon tetrachloride (high-density difference), it turned out to be the best hint available. At a certain rate this solvent bubbling would increase sharply. The bubbling usually occurred near the center of the column and would build up there to a high degree of agitation. The layer of bubbling would gradually grow up the column without any change in either velocity. When the bubbling reached the top of the packing a layer of water would appear above the packing. This was designated as the flooding point. If the column were kept in operation beyond this point the water

layer would build up and would have proceeded out the top of the tower with the solvent layer if the rates were not

lowered.

In series 13 the water phase was opposite and a carbon tetrachloride-petroleum solvent mixture with a density of 1.52 g./cc. was the adjacent phase. Exceedingly high rates were obtained in this series before flooding. Even at rates considerably below flooding the column was greatly agitated with bubbles of solvent moving in all directions. The bubbles were quite small in general, though they continually changed in size and shape. The appearance of the column under these conditions was the best from an extraction standpoint of any with water as the opposite phase. In this series flooding was characterized by the appearance of a layer of water below the packing. Special care had to be taken to locate the exact flooding point since there was no marked change in the appearance of the column just before flooding as in the other series. It was quite easy in this series to go right past the flooding point since flooding usually took several minutes to develop as previously explained. This slow development of flooding might account for an anomaly in the data of Breckenfeld and Wilke (7). Their data were well correlated by the grouping of variables shown in Figure 4 with the exception of those of the series carbon tetrachloride-water. In this case the reported flooding points were some 30% above the correlation.

Ballard and Piret (4) described the appearance of their column during its operation. They noted that there was only a slight pulsation in the column at rates below flooding when water was the opposite phase. They made no mention of any solvent bubbling through a continuous water layer under these conditions.

Blanding and Elgin (6) also made no mention of any appreciable drop formation with the water phase as the opposite one. However, Breckenfeld and Wilke (7) in their one series with water as the opposite phase noted that at the flooding point drops of carbon tetrachloride passed down through the water.

The amount of bubbling which occurred in the column prior to flooding is a function of the water velocity. At low water to solvent ratios the column stayed quiet almost up to the flooding point. At high water to solvent ratios

the maximum water holdup was greatly increased before flooding occurred and hence the solvent bubbling effect.

At high water rates the effect of the position of the interface was quite important. At rates below flooding the column could be made to flood by changing the position of the interface. Apparently this was equivalent to changing the velocity of one of the phases. The flooding could be made to disappear by returning the interface to its original position. Therefore, so as not to be misled by this false flooding, extra care was taken to keep the interface in the same location throughout the run. The effect of the position of the interface seemed to be less important when the water solvent velocity ratio was low.

Observations made in the preceding paragraphs were independent of the size of the packing used in this study.

SOLVENT AS OPPOSITE PHASE

When the solvent phase was opposite it bubbled up or down, as the case may be, through the column. Here, since the solvent did not wet the packing, bubbles were seen at even the lowest rates. However, in many of the runs as either rate increased the solvent holdup increased and the bubbles coalesced. This resulted in giving the column a less agitated appearance. Upon further increase of velocity the agitation began to increase since the solvent became continuous in spots and both solvent and water bubbles were seen. The water bubbles differed in appearance from the solvent bubbles. They were not discrete but appeared to be small gaps in the continuity of the solvent. This was generally the appearance of the column just prior to and at the flooding point.

Ballard and Piret (4) described the flow behavior when the solvent phase was the opposite one. They noted that three distinct types of flooding mechanism took place. In this research the flooding point was that at which a definite solvent layer appeared above or below the packing but at the opposite end of the column from the interface. Some phase inversion always preceded this flooding, even at low-solvent rates. No behavior, corresponding to the "slugging" mechanism of Ballard and Piret, was ever noted. The mechanism observed in this study seemed quite similar to that described by Blanding and Elgin (6).

The position of the interface was somewhat harder to control for these runs than for those where the water was the opposite phase. At the same time the false flooding mentioned in a previous paragraph was a greater hazard in these series. The flooding

Fig. 5. Correlation of data of Sherwood, Shipley, and Holloway.

point seemed especially sensitive to the position of the interface and care was maintained to see that the interface remained stationary as the column approached the flooding point. Meager data that have led previous investigators to the conclusion that higher flooding points were attainable when the water phase was the opposite one may be due to this false flooding, which would account for lower values when the solvent phase was opposite.

EFFECT OF DROP SIZE

High density difference and low interfacial tension are the chief contributors to high flooding velocities. It is significant that in both of these cases the drop sizes were relatively small. For a given size nozzle and packing size the drop size decreased with increased density difference and decreased interfacial tension. The drop size seemed to be much more a function of the physical properties of the two liquids than of the packing size. In fact for those series where methyl ethyl ketone was added to lower the interfacial tension, the drop size was much smaller than the interstices of the 1-in. packing. Of course, as the rates increased, coalescence caused the drop size to grow but not until much higher rates were obtained than for systems with higher interfacial tensions. The same was true for the systems of high density difference. This correlation of small drop size and high flooding velocities held true with either phase adjacent or opposite.

HOLDUP

A certain amount of holdup of the opposite phase in the column always occurred. The amount of holdup prior to flooding seemed to be a function of the ratio of opposite to adjacent veloci-

ties. At high ratios the holdup may exceed 70% of the total tower volume. This means that the so-called dispersed phase predominated in the column usually as a result of a phase inversion, which made the originally dispersed phase mostly continuous. Although quantitative determinations of holdup were not made, some values were estimated at the flooding point. The amount of holdup seemed independent of which phase was adjacent and which opposite for a given velocity ratio and for a given system. Also, the amount of holdup seemed to be independent of the packing size, but dependent on the nature of the liquids. The high viscosity fluids appeared to coalesce more and hence to have a greater holdup at flooding even though this flooding took place at lower rates.

PRESSURE DROP

Pressure-drop readings were taken during all the runs. They seemed to be a function of the amount of holdup in the column. As such they were sometimes useful in helping to determine the approach of flooding. However, visual appearances were a much better indication. Although there was an increase in pressure drop at flooding velocities, this usually occurred after the layer of opposite phase was observed above or below the packing. Nevertheless, in some runs it did precede the visual observation and as such was useful. The magnitude of the pressure drop could not be correlated to flooding and seemed to be largely a function of holdup which in turn, as indicated above, was primarily a function of velocity ratios. This inability to correlate pressure drop with flooding velocity agrees with previous investigators of liquid-liquid flooding behavior. However, it is contrary to the successful results obtained by White (20) and others with gas-
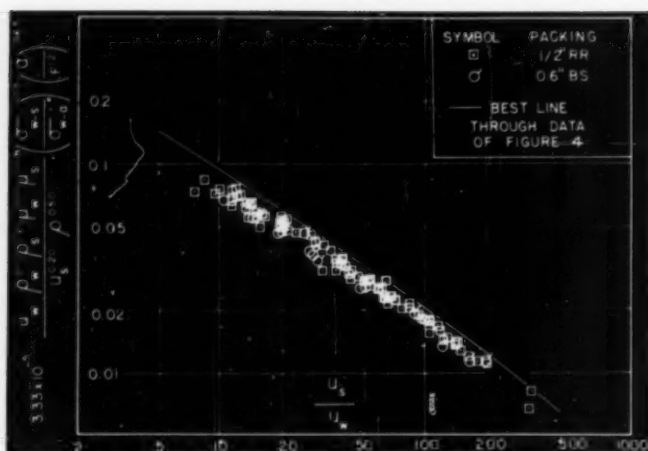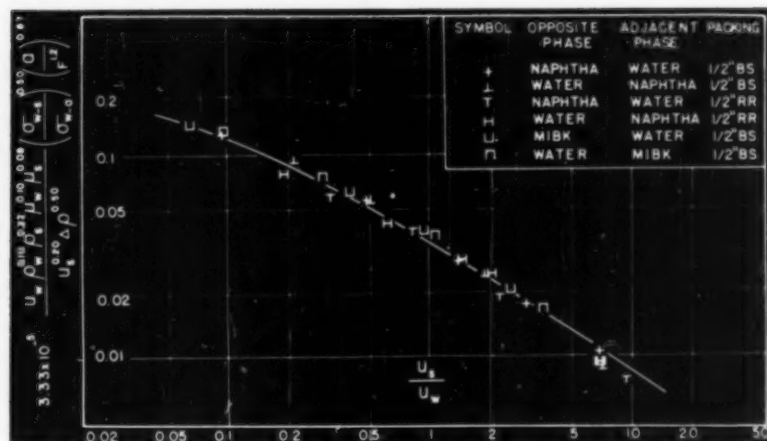
Fig. 6. Correlation of data of Blanding and Elgin.

liquid systems. Here a sharp increase in pressure drop was noted at flooding.

The maximum pressure drop is usually quite small in liquid-liquid flow in packed columns, even at the flooding point. This figure never exceeded 40 cm. of fluid (for 6 ft. of packing height) and should not be a disturbing factor in column design.

Conclusions

The aims of this investigation as expressed at the beginning of this study were attained with the following results:

1. The original data on liquid-liquid flooding cover a wider variation in physical properties than any heretofore reported in the literature.

2. All the data reported here and elsewhere on both liquid-liquid and gas-liquid flooding velocities are brought together within a mean deviation from the calculated flooding velocity of 10.2% by this new dimensionally consistent correlation.

3. Observations of the flow behavior of the various liquids were made, and a discussion of these observations indicates that

a. The appearance of the column prior to flooding differs depending upon which phase is adjacent and which is opposite, but the magnitude of the actual flooding points is independent of this.

b. Flooding is characterized by the appearance of a layer of the opposite phase at the far end of the column from the interface. This occurs regardless of which phase is opposite.

c. Raising or lowering the interface may cause premature flooding.

d. Maximum flooding points occurred when the drops of the opposite phase are the smallest. Small drops are caused by large density differences or small interfacial tensions.

e. The holdup of the opposite phase in the column at flooding is a function of the ratio of velocities and seems independent of which phase is adjacent or opposite and of the size of the packing. The opposite phase holdup may be greater than 70% of the tower volume.

f. Examination of the change in the pressure-drop readings prior to flooding may give a hint as to the approach of flooding, but this is not so good an indication as is a visual determination. The pressure drop seems to be a function of the holdup and cannot be used to correlate flooding velocities.

Notation

a = sq.ft. packing surface/cu.ft. packed volume

F = cu.ft. void volume/cu.ft. packed volume

$f(R)$ = ordinate of Figure 4

g = acceleration due to gravity, 32.2 ft./sq.sec.

k = exponent of F in the dimensionless combinations

m = exponent of dimensionless term $u_w^2 a/g$

n = exponent of dimensionless term $u_s^2 a/g$

p = exponent of dimensionless term ρ_s/ρ_w

q = exponent of dimensionless term $\Delta\rho/\rho_w$

R = volumetric flow ratio, u_s/u_w

r = exponent of dimensionless term $u_w\rho_w/\mu_w a$

s = exponent of dimensionless term $u_s\rho_s/\mu_s a$

t = exponent of dimensionless term $\sigma_{w-s}/\sigma_{w-a}$

u = velocity of either phase through the column, cu.ft./hr. sq./ft. of tower cross-section

ρ = density of either phase, g./cc.

μ = viscosity of either phase, centipoises

σ = interfacial tension, dynes/cm.

$\Delta\rho$ = density difference, g./cc.

SUBSCRIPTS

s = solvent phase for liquid-liquid systems and gaseous phase for gas-liquid systems

w = aqueous phase for liquid-liquid systems and liquid phase for gas-liquid systems

$w - s$ = interfacial tension between aqueous and solvent phases

$w - a$ = interfacial tension between aqueous phase and air

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Chemical Engineering Progress and the Symposium Series have offered chemical engineers advice on communication from a variety of people, including management executives, chemical engineers, and psychologists. Now CEP presents a series of articles by a professor of writing who is also an editor of technical manuscripts.

Professor H. J. Tichy has given writing courses for twenty years at Hunter College, has trained young writers in journalism and creative-writing courses in private schools in New York City, and has given private and group instruction in writing to business executives, Ph.D. candidates, and teachers. Dr. Tichy, who has been a news writer, copywriter, publicity and public relations director, and editor, spent nearly three months in the office of a technical journal preparing for this series of articles by reading the manuscripts and published works of chemical engineers.

Engineers Can Write Better

Part I

H. J. Tichy   Hunter College of the City of New York

Peter Pilot, B.Ch.E. '36, shook two pills out of the bottle. His headaches and lack of energy were beginning to interfere with his work. Only yesterday the director of research had warned him that his work at the plant was poor. Pete threw the pills down his throat, swallowed some water, and decided to stop at the drugstore to get something to give him energy.

The drugstore clerk sold him two bottles of vitamin pills with promises of increased energy and vitality and a return of hair and youth. After a week of pills, Pete, feeling no better, tried the tonic that had helped the personnel manager, who had once been forty pounds underweight after flu.

A few days later Pete bought a book on home medicine. He might have gone to a doctor, but he had not seen a doctor since his college days, when the university physician had insisted on tonsil removal and a low-starch diet. The tonsil operation had made Pete uncomfortable for a week, and the diet—well, maybe he was a little paunchy now, but he hadn't needed a doctor in all these years, had he?

Pete bought a gargle, a tonic, and some liver pills recommended in his book of home medicine and started going to a gymnasium near the plant three nights a week. On Saturday and Sunday mornings he played tennis again after ten years of inactivity. When he felt tired, he took extra vitamin pills.

Joe Doakes suggested health foods, and Pete ate them and drank large quantities of fruit juice during the day. A week later he had indigestion, which was not lessened by pills, powders, or emulsions. One afternoon after extra doses of all his drugs, he collapsed at the plant.

The family doctor after a look at Pete and his home pharmacy ordered him to the hospital for treatment of assorted ills from overdoses of vitamins, overuse of drugs, injudicious exercise, and unaccustomed foods. As one scientist to another, he told Pete a few unwelcome truths and promised to look into the original complaint as soon as Pete was back in shape. "But," he concluded, "all you probably need is to cut down on your eating, particularly starches and sweets."

There Must Be an Easier Way

No B.Ch.E. would be so easily gulled by advertising and quacks? Perhaps not in matters of health. But what happened when Pete found that his poor writing was interfering with his advancement at the plant? What did he try? Whom did he consult? Certainly not his dusty freshman handbook of English. Definitely not any recollections of his freshman English class and the professor who had advised him to read more and had cut all the slang out of his themes.

Pete had lunch with an industrialist who was in demand as a convention speaker. The industrialist recommended short sentences and the you-approach. Pete put the simple advice to use immediately, and soon his sentences sounded as though they had been constructed by a mentally retarded six-year-old. The you-approach got some odd looks from workmen at the plant and a veto from Pete, Jr. "You're always telling me what I think and what I want, Dad. You know something? When you do, I don't."

On the glowing advice of a business executive famed for his excellent letters, Pete turned to short words and active verbs. The executive also took Pete to a reading course. After a few sessions Pete bought a machine to increase his reading speed and thus improve his writing. (By this time Pete, trained to simplicity, would have said that he wanted to read faster but the reading instructor, who apparently did not belong to the simplicity school, always used the phrase *increase one's reading speed.*) Pete read for a week with the gadget, which measured his speed, covered what he had read with eye-resting green felt, pointed red arrows at what he was to read next, and turned pink to predict a change in the weather. At the end of the week it became an expensive but suitable accessory for Junior's space suit.

Then Pete read an article on how to make his writing readable. As the article illustrated how to compute readability by the use of an equation, Pete felt encouraged. That equation was familiar ground, and Pete, hopefully attacking his writing with a desk calculator, an adding machine, and graph paper, succeeded so well in making his style the acme of readability that the director of research suggested that Pete write primers for first-grade children in his free time.

There was an ominous note in that phrase *free time*, and so Pete in desperation sought help from a copywriter related by marriage to his wife's second cousin. The fashion writer listened sympathetically to Pete's woes.

"Brother," she said, "you can't put every idea into one type of sentence or vocabulary any more than you can put every woman into one style. Now, obviously this man you're writing for is an egghead and wants the intellectual approach. You need a good dictionary, a thesaurus, and a book of synonyms. Anyone who can use scientific terms the way you do ought to be able to floor him with intellectual vocabulary."

Pete obediently studied the dictionary, lost himself in the thesaurus, and read the book of synonyms with amazement. He learned that he had always mispronounced *abacus* and soon acquired an impressive vocabulary of words beginning with *a* and *b*. At a research conference he tried the new vocabulary on an audience used to scientific jawbreakers and impressed everyone. In fact, he had to leave early to escape the kidding.

Poor Pete in search of a writing panacea is less to blame than is Pete looking for a medical cure-all. When he injudiciously consumes vitamin pills and

drugs, Pete is rightly blamed for his folly, but when he is foolishly tempted to use only short sentences or fancy diction, he is, like the erring girl in the song, more to be pitied than censured.

Writing Needs of Chemical Engineers

His problem is serious. On Pete's ability to prepare clear, effective reports and summaries his success may depend. But who is there for him to consult about his writing troubles? He is offered advice from all corners—from chemical engineers with very little knowledge of how to teach writing, from writing teachers who know nothing of chemical engineering, and from executives with little knowledge of either. He is told how to write by teachers fascinated by big business, by psychologists wanting to be teachers, and by businessmen intrigued by elementary psychology. No wonder Pete feels as though he has been on a merry-go-round. He has.

A strong need makes engineers seek everywhere for help in learning to write better. At conventions they speak frankly of their writing problems. Their employers plead, "How can we get chemical engineers to write better?" Editors who read papers submitted for publication want to know, "Why don't they learn to write?"

Perhaps the answer is that, like Pete, they are looking for a panacea. But writing is not a trick to be learned quickly or an esoteric art dependent on the inspiration of Greek gods. Learning to write, like studying for Pete's profession, requires time and effort. Competent writers are often amazed and amused by the popular assumption that a trick or magic or a quick formula is the answer. One can no more improve one's writing without time and effort than one can by magic solve quadratic equations, perfect a tennis serve, or master a foreign language. All good writing requires work, sometimes the most demanding kind. A tennis or golf stroke that looks easy is the result of long practice. It would be foolish for a beginner to expect to achieve the ease of champion players or professional writers without working as hard.

Once the chemical engineer is ready to work, he needs instruction suited to him and to his writing. He is a professional man of advanced education. When he writes for his fellow engineers, he has readers of superior intellect and education. Baby sentences and elementary words, which may be appropriate for readers of less intelligence and inferior education, are inappropriate for those who are able to read material as difficult as chemical engineering textbooks. Mistakes in grammar and rhetoric which might go unnoticed

in a business letter glare and blind like searchlights in a technical report or an article in a professional journal. Worse still, they interfere with the reader's understanding. It is of major importance that the chemical engineer write clearly, for in scientific writing there is no place for ambiguity and vagueness, and readers of technical articles should not have to reread sentences which are carelessly or badly written. The chemical engineer, therefore, urgently needs to know how to avoid errors and weaknesses that interfere even temporarily with the reader's comprehension.

In an attempt to help chemical engineers to improve their writing, this article is based on months of reading and analyzing what chemical engineers write. The principles considered and suggestions made concern the mistakes and weaknesses in material that came to the desk of the editor of a technical journal. No time is wasted on the errors in other types of writing. The examples and illustrations come almost exclusively from papers submitted for publication in engineering journals, and the emphasis throughout is not on writing in general but on the writing of chemical engineers.

The author strongly believes that with a little effort expended properly a chemical engineer can learn to write better. Most of the poor English and poor writing in engineering papers can be corrected and improved by intelligent application of a few principles which engineers commonly ignore or misunderstand. These principles are not numerous or difficult, and applying them results in immediate, encouraging improvement.

The Time to Revise

An analysis of a hundred papers on chemical engineering reveals that at least half the mistakes and weaknesses concern sentence structure. Accordingly sentences will be considered first. The chemical engineer who wishes to write better is urged to study the discussion and examples, to search his own writing for similar flaws, and to correct them as illustrated. Sentence errors are best checked after an article is complete. Consciously trying to shape every sentence correctly and effectively while writing the first draft is frustrating even to experienced writers. It distracts the writer's thoughts and dams his flow of words.

When the first draft is complete, the writer should put it aside for at least twenty-four hours, preferably for three or four days, and then examine the sentences carefully. An immediate attempt to correct sentences is usually less thorough and accurate because the writer often sees not what he

put on paper but what he had in mind. This possibility of confusion between the image in the mind and the object produced exists at the time of creation; after a cooling-off period the creator is more critical.

Dangling with the Greatest of Ease

The most prevalent error in the hundred chemical engineering papers studied is a mistake which confuses and irritates readers—the poor arrangement of words in sentences. The most frequent mistakes in engineering papers are dangling modifiers; in fact, engineers often leave modifiers dangling by less than a single hair or even suspended in outer space. The *ing* form of the verb as in *using, speaking, lacking, boiling,* etc., is frequently misplaced. When a sentence begins with a phrase containing one of these *ing* forms of the verb used as an adjective, the part of the sentence that the form describes must come next and must be the subject of the sentence.

A chemical engineer touring New York City knows that there is something wrong when he says, for example,

Flying high over the city in our airplane, the Empire State building looked like a toy.
(1—Incorrect)

He knows that the Empire State building was not flying. He may correct his sentence by placing the proper word after *flying high over the city in our airplane:*

Flying high over the city in our airplane, we noticed that the Empire State building looked like a toy. (1—Correct)

or he may eliminate the troublesome *ing* form:

Viewed from an airplane high over the city, the Empire State building looked like a toy.
(1—Correct)

Poor word order does not always result in the obviously ridiculous, but it does annoy and often confuse the intelligent reader. Engineers seem unsuspicious of the *ing* form when they write sentences like

Lacking any better means, radioactive particles had to be removed by brute force.
(2—Incorrect)

Using mass-transfer coefficients and these property values, Nusselt, Schmidt, and Grashof numbers were calculated for each experiment. (3—Incorrect)

Instead of using a commercial preamplifier, a cathode follower built in this laboratory may be substituted. (4—Incorrect)

In sentence (2) the *particles* are said to *lack any better means;* in (3) and (4) the *numbers* and the *cathode follower* are *using.* The sentences may be corrected by the methods given for

sentence (1)—eliminating the *ing* form or placing the proper word after the *ing* form.

> For want of any better means, radioactive particles had to be removed by brute force.
>
> (2—Correct)

> Using mass-transfer coefficients and these property values, the writer calculated Nusselt, Schmidt, and Grashof numbers for each experiment.
>
> (3—Correct)

> A cathode follower built in this laboratory may be substituted for a commercial preamplifier.
>
> (4—Correct)

> Instead of using a commercial preamplifier, the writer chose a cathode follower built in this laboratory.
>
> (4—Correct)

In chemical engineering papers phrases like *in Figure 1*, *in Table 1*, or *on line C* are often too far from the words they describe. Words, phrases, and clauses should always be placed so that their relationship is immediately clear. A chemical engineer writes,

> The enthalpies of the three mixtures in the vapor phase . . . are calculated for each of the ternary mixtures by the two methods mentioned above and are compared with the values obtained from the experimental data in Table 4.
>
> (5—Weak)

In this sentence the experimental data seem to be in Table 4, but the writer means to convey that experimental values and enthalpies are compared in Table 4. Moving the phrase *in Table 4* makes the sentence clear immediately:

> The enthalpies of the three mixtures in the vapor phase . . . are calculated for each of the ternary mixtures by the two methods mentioned above and are compared in Table 4 with the values obtained from the experimental data.
>
> (5—Improved)

Often a writer places before *it* a phrase which does not logically describe *it*.

> As chief of this department, it has been my pleasure to supervise research. (6—Incorrect)

> As chief of this department, I have supervised research. (6—Correct)

Only One Place

The accurate placing of the word *only* in scientific manuscripts is very important. Sweeping changes in meaning occur when *only* is shifted from one place to another, as moving *only* in the following sentence illustrates:

> Only I calculated the value of x in the equation.
>
> (7a)

> I only calculated the value of x in the equation.
>
> (7b)

> I calculated only the value of x in the equation.
>
> (7c)

> I calculated the only value of x in the equation.
>
> (7d)

> I calculated the value of only x in the equation.
>
> (7e)

> I calculated the value of x only in the equation.
>
> (7f)

> I calculated the value of x in the only equation.
>
> (7g)

Reading these sentences aloud shows how the meaning varies with the position of *only*. In sentence (7a), for example, the writer is the only person who calculated the value of x in the equation; in sentence (7d) x has only one value in the equation; sentence (7g) states that there is only one equation. Attaching *only* to the wrong idea may result in dangerous mistakes in scientific writing. The chemical engineer should, therefore, examine carefully the position of *only* in his sentences. Whenever a possibility of misunderstanding exists, *only* must be placed directly before the concept it describes.

Agreement Between Subjects and Predicate Verbs

A second common error in the sentences of engineers is lack of agreement in number between subjects and predicates. When the need for agreement is obvious, chemical engineers do not err; they do not write, for example, "These methods is recommended," or "The mixture are boiled." But a few words coming between the subject and predicate, an unusual arrangement of words, or a phrase attached to the subject easily leads engineers into errors. In the papers on the editor's desk the following mistakes appear:

> An over-all analysis of results indicate . . . .
>
> (8—Incorrect)

> A detailed description of the copper deposition studies have been reported elsewhere.
>
> (9—Incorrect)

> Where a fluid flows in laminar motion through a porous bed, estimation of the pressure drop and fluidization characteristics are desirable.
>
> (10—Incorrect)

> The second class of depth and type filters are termed oriented or graded density filters.
>
> (11—Incorrect)

> The excellent agreement between the values substantiate the accuracy of the latent heats.
>
> (12—Incorrect)

> An appropriate combination of three major factors—namely, motivation, ability, and personality, are significant determinants of success with people. (13—Incorrect)

Obviously words standing between the subject and predicate confuse many engineer-writers. The writer of sentence (8) would probably never say, "The over-all analysis indicate . . . ," but as soon as *of results* stands between subject and predicate, he is confused. The corrected sentences with subjects and predicates in dark type follow:

> An over-all **analysis** of results **indicates** . . .
>
> (8—Correct)

> A detailed **description** of the copper deposition studies **has been reported** elsewhere.
>
> (9—Correct)

> . . . **estimation** of the pressure drop and fluidization characteristics **is** desirable.
>
> (10—Correct)

> The second **class** of depth and type filters **is termed** oriented or graded density filters.
>
> (11—Correct)

> The excellent **agreement** between the values **substantiates** the accuracy of the latent heats.
>
> (12—Correct)

> Three major **factors** combined, namely motivation, ability, and personality, **are** significant determinants of success with people.
>
> (13a—Correct)

> An appropriate **combination** of three major factors—namely, motivation, ability, and personality, **is** a significant determinant of success with people. (13b—Correct)

A writer who has difficulty finding subjects of sentences might try diagramming sentences if he is one of those fortunate persons who once learned to diagram. If he is not, he might locate the verb and construct a question. In sentence (8—Correct), for example, the verb is *indicates*. "Who or what indicate or indicates?" he should ask himself. "The *analysis*; therefore the verb should be *indicates*, the singular form." In the same way he might ask for sentence (11—Incorrect), "Who or what is or are termed oriented?" "The second class *is* termed oriented."

To avoid being confused by intervening terms the writer answering these questions must use the whole phrase in which a word appears. In sentence (11) the whole expression *of depth and type filters* is obviously not the subject; therefore *the second class* is the only remaining possibility.

On Data, the Engineer's Headache

In the war of agreement between subject and predicate many chemical engineers bear permanent battle scars from struggling to use *data* as a plural noun. No doubt most of them were taught, apparently unforgettably, that the words *data*, *strata*, and *phenomena* are the plurals of *datum*, *stratum*, *phenomenon*. The corrections in manuscripts show that chemical engineers are constantly battling against a tendency to use *data* as a singular noun. Usually the war is won by crossing out singulars before a manuscript reaches the editor's desk, but occasionally engineers lose a skirmish by using plural verbs and forgetting to use plural demonstrative adjectives and pronouns for *data*:

> This data are
>
> (14—Incorrect)

> These data are
>
> (14—Correct)

These data for heat transference are reported in Table 5 and shown in Figure 2. It is also compared with data from other sources. (15—Incorrect)

These data for heat transference are reported in Table 5 and shown in Figure 2. They are also compared with data from other sources. (15—Correct)

Similarly, a plural construction should be used with such words as *phenomena, strata,* or *maxima.*

The maxima in the hold-up curves for these cases is attributed. . . . (16—Incorrect)

The maxima in the hold-up curves for these cases are attributed. . . . (16—Correct)

The long hard Data War is coming to an end, for the new handbooks of English witness a truce. In all except the most formal writing *data* is now acceptable in the collective sense as a singular noun.

Data for copper deposition has been given previously. (17—Now Accepted as Correct)

One should not however use the same *data* in the plural and in the singular. Engineering journals, being conservative and formal in their use of English, will probably continue for some time to use *data* only as a plural noun. But elsewhere editors will be less likely to object to it in a collective singular sense, and the chemical engineer may with a sigh of relief use *this data is* in his reports and letters. The authorities are on his side at last.

Comparing Correctly

A serious common fault in scientific writing is failure to express comparisons logically. When *than* completes a comparison, it may be necessary to add a word to avoid ambiguity.

In the overlapping areas Wilip's results were given more weight since they were in better agreement with Beattie's than those of Ramsey and Young. (18—Incorrect)

In the overlapping areas Wilip's results were given more weight since they were in better agreement with Beattie's than were those of Ramsey and Young. (18a—Correct)
or

In the overlapping areas Wilip's results were given more weight since they were in better agreement with Beattie's than with those of Ramsey and Young. (18b—Correct)

Sentence (18—Incorrect) has two possible meanings; each correction has one unmistakable meaning. The writer is obligated to say exactly what he means.

These filters are better than any filters. (19—Incorrect)

These filters are better than any other filters. (19—Correct)

The errors in the sampling technique are greater than Table 5. (20—Incorrect)

The errors in the sampling technique are greater than those in Table 5. (20—Correct)
or

The errors in the sampling technique are greater than Table 5 shows. (20—Correct)

An Old Error of Chemical Engineers

Another weakness in the papers studied is incomplete parallelism. Several ideas of equal value are expressed in the same grammatical form, even perhaps in similar phrasing; then the construction breaks down and one idea tags along in a different construction. Correct parallel constructions are useful for indicating similarity in the value of ideas, and they help the reader to grasp a series of ideas easily.

Besides being cheaper, the cathode follower is simpler in design and easier to maintain than the commercial preamplifier. (21—Correct)

The writer of sentence (21—Correct) conveys three ideas in the form of comparative adjectives—*cheaper, simpler, easier*—but many engineers, failing to see the parallelism, would express the thought this way:

The cathode follower has a simpler design. The writer found it easier to maintain. It also costs less than the commercial preamplifier. (21—Weak)

In (22—Incorrect) the sentence elements joined by *and* are not parallel in expression; therefore to connect them by a coordinating conjunction such as *and, or, for, nor, but* is misleading:

This is a group with technical training and acquainted with procedures. (22—Incorrect)

This group has technical training and a knowledge of procedures. (22—Correct)

This is a group with technical training and an acquaintance with procedures. (22—Correct but awkward)

Unequal elements connected by coordinating conjunctions appeared early in the history of chemical engineering. A hoary definition of a chemical engineer illustrates this common error:

. . . a person possessing a knowledge of chemistry, physics, and mechanics and who employed that knowledge for the utilization of chemical reactions on a large scale. (23—Incorrect)

. . . a person who employs his knowledge of chemistry, physics, and mechanics for the utilization of chemical reactions on a large scale (23a—Correct)
or

. . . a person who possesses a knowledge of chemistry, physics, and mechanics and who employs that knowledge for the utilization of chemical reactions on a large scale (23b—Correct)

. . . a person possessing a knowledge of chemistry, physics, and mechanics and employing that knowledge for the utilization of chemical reactions on a large scale. (23c—Correct)

Sentence (23 Incorrect) connects the unequal forms *possessing* and *who employed* by *and*, sentence (23a Correct) eliminates the *and* for terse expression, sentence (23b Correct) connects the parallel constructions *who possesses* and *who employed* by *and*, and sentence (23c—Correct) connects *possessing* and *employing* by *and*.

Marked Improvement Possible

Even though errors are long standing, they need not continue. In fact, all of the sentence errors analyzed in this article may be easily eliminated. After correcting them a few times in his work the engineer will find that he seldom makes the mistakes in writing and that later he avoids them even in his extemporaneous speaking; as a result his speaking and writing will be smoother, easier, and clearer.

The improvement promises to be great because the errors analyzed in this paper comprise nearly two thirds of the major errors found in a survey of chemical engineering papers submitted for publication or presented at professional meetings. It is likely, therefore, that the chemical engineer who corrects them will remove at least one half of the errors in his writing. The writer who eliminates errors has written a paper that at least can be understood. Correct English is clear English.

But not all correct sentences are effective sentences; sometimes the expression is still weak. By using devices for emphasis the writer can make a stronger impression. Peter Pilot has been told this often in articles and speeches, but too frequently this advice, like the suggestions that he take vitamin pills, tonics, and health foods, has been so generalized and indiscriminate as to be dangerous. Teachers of writing who help adults unlearn bad habits know just how dangerous. Enough nonsense about sentence emphasis has been circulated in the past few years to confuse a whole profession of Peter Pilots. Because of the existing misunderstanding, faulty instruction, and confusion, Part II of this article will consider questions like, Must engineers write short sentences? How simple should engineers' sentences be? What are the typical weaknesses of engineers' sentences? What should the engineer-writer know about the long sentence and the short sentence?

Part II of this series, "The Long and the Short of It," will be published in a forthcoming issue.

ALUMINUM ALLOY REFERENCE SHEET

HARRY W. FRITTS — Aluminum Company of America, New Kensington, Pa.

Wrought Alloys 4S, Alclad 4S, and 50S

Commercial Products:
4S—Sheet, plate, tube, pipe.
Alclad 4S—Sheet, plate.
50S—Sheet, plate, tube.

Applications and Remarks: Alloy 4S is used where slightly more strength than 3S is desired with the same relative resistance to corrosion. Alclad 4S is used extensively for industrial building sheet because of its excellent resistance to corrosion and good mechanical properties. It is composed of a 5% coating of 72S alloy over the 4S alloy core. Alloy 50S is intermediate between 3S and 4S in strength and has about the same relative resistance to corrosion. Its principal use in the process industries is for aluminum instrument tubing. This tubing compares favorably in performance with annealed copper instrument lines and costs considerably less. These alloys are included in section 8 of the 1952 A.S.M.E. Boiler and Pressure Vessel Code.

Composition:
4S—1.2% Mn, 1.0% Mg, balance Al

ALUMINUM ALLOY

A.S.T.M. ALLOY DESIGNATIONS:

4S	— MG11A
Alclad 4S	— Clad MG11A
50S	— G1A

A.S.T.M. SPECIFICATIONS:

B178, B209, B210, B274

Alclad 4S—72S cladding is 1% Zn, balance Al—core is same as 4S
50S—1.4% Mg, balance Al

MECHANICAL PROPERTIES:

	Temper Designations					
	4S and Alclad 4S			50S		
	—0	—H34	—H38	—0	—H34	—H38
Tensile strength, lb./sq.in.	26,000	34,000	40,000	21,000	28,000	32,000
Yield strength, lb./sq.in.	10,000	27,000	34,000	8,000	24,000	29,000
Elongation—% in 2 in. (1/16 in. sheet)	20	9	5	24	8	6
Shear strength, lb./sq.in.	16,000	18,000	21,000	15,000	18,000	20,000
Brinell hardness — 500 kg. load, 10 mm. ball	45	63	77	36	53	63

PHYSICAL PROPERTIES:

	4S and Alclad 4S	50S
Modulus of elasticity, lb./sq.in. —	10,000,000	10,000,000
Specific gravity	2.72	2.69
Weight—lb./cu.in.	0.098	0.097
Melting range, F.	1165°-1205°	1160°-1205°
Thermal conductivity—B.t.u./(hr.)(sq.ft)(° F.)	1132 (—0)	1335 (—0)
	1132 (—H38)	1335 (—H38)

Average coefficient of thermal expansion — in./°F. x 10⁻⁶

	4S and Alclad 4S	50S
—76° — +68°	11.9	
68° — 212°	12.9	13.2
68° — 392°	13.4	13.8
68° — 572°	13.9	14.3

Electrical conductivity—

	4S and Alclad 4S	50S
% of International Annealed	42 (—0)	46 (—0)
Copper Standard	42 (—H38)	46 (—H38)

Formability: These alloys have good forming characteristics; however they are slightly harder to form than the comparable tempers in 3S. They can be machined using high machine speeds and high rake angle. Cutting will be slightly less stringy and weaker than 3S cuttings.

Heat Treatment: Wrought alloys 4S, Alclad 4S, and 50S are all non-heat-treatable. Their strengths are increased by cold working. The properties of the intermediate and hard tempers are stabilized by treatment at a slightly elevated temperature.

Weldability: These alloys can be welded by all the common methods. Inert gas shielded arc welding is preferred where flux removal presents a problem. Alloys 4S and Alclad 4S should be welded with alloy 4S, 43S, or A54S wire. Alloy 50S is normally welded with parent material, 43S, or A54S wire.

CORROSION RESISTANCE

ACIDS

Acetic, all concs., r.t.*	E
Acetic, other than glacial, boiling	P
Acetic glacial, boiling*	E¹
Acetic anhydride, r.t.*	E
Acrylic, glacial, r.t.*	E
Benzoic, sat. soln., boiling*	E
Boric, 7% soln., 180° F.*	E
Butyric, all concs., r.t.*	E
Butyric anhydride, r.t.*	E
Carbolic (phenol), all concs., to 240° F.*	E
Carbonic, all concs., r.t.*	E
Chromic, below 10%, r.t.	G
Cresylic (Cresol), r.t.	E
Fatty, up to boiling*	E¹
Hydrochloric, all concs.	N
Hydrocyanic, all concs., r.t.*	E
Hydrofluoric, anhydrous, 200° F.*	E
Hydrofluoric solutions	N
Lactic, anhydrous, r.t.*	E
Lactic, up to 10%, r.t.*	E
Maleic, 30%, r.t.	E
Maleic anhydride, molten*	E
Malic, to 50%, r.t.	E
Naphthenic, up to 180° F.*	E¹
Nitric, above 82%, to 120° F.*	E
Nitric, below 82%, r.t.	P
Nitric, red fuming, up to 120° F.*	E
Oleic, up to boiling*	G
Oxalic, all concs., r.t.*	P
Oxalic, all concs., elevated temperature	N
Phosphoric, all concs.	E
Phthalic, molten	E
Phthalic anhydride, molten*	E
Propionic, all concs., r.t.*	E
Propionic anhydride, r.t.*	E
Stearic, up to boiling*	E¹
Sulfuric, fuming	G
Sulfuric, other than fuming	N
Sulfurous, r.t.	F
Tannic, all concs., pure, r.t.	E
Tartaric, all concs., r.t.*	E

ALKALIES

Ammonium hydroxide, comm'l., r.t.*	E
Calcium hydroxide, all concs.	P
Potassium hydroxide, all concs.	N
Sodium hydroxide, all concs.	N

ALKALINE SALTS

Potassium carbonate, all concs.	P
Sodium bicarbonate, r.t.*	E
Sodium carbonate, all concs.	P
Sodium sulfide	P

NEUTRAL SALTS

Calcium chloride, all concs., to 200° F.*	G⁺²

RATINGS:

E—Excellent resistance. 0.001 max. in./year of penetration. Corrosion so slight as to be harmless.

Calcium sulfate, sat. soln., r.t.*	G⁺
Calcium sulfide, all concs., r.t.*	G
Magnesium chloride, all concs., r.t.	G⁺
Magnesium sulfate, to 50% soln., r.t.	G
Potassium chloride, all concs., r.t.	G⁺²
Potassium nitrate, all concs., r.t.	E
Potassium sulfate, all concs., r.t.	E
Sodium chloride, all concs., r.t.*	G²⁺
Sodium nitrate, all concs., r.t.*	E
Sodium sulfate, all concs., r.t.	E

ACID SALTS

Alum, paper makers, r.t.*	E
Aluminum chloride, dry, 70° F.	G
Aluminum chloride, moist	P
Aluminum sulfate, r.t.*	P
Ammonium chloride, all concs., r.t.*	G⁺
Ammonium nitrate, all concs., to 285° F.*	E
Ammonium sulfate, all concs., r.t.*	E
Copper chloride, nitrate, sulfate	P⁺
Ferric chloride, nitrate, sulfate	P⁺
Lead chloride, nitrate, sulfate	N⁺
Mercury salts	P⁺
Nickel chloride, nitrate, sulfate	P⁺
Silver salts	P⁺
Stannous and stannic salts	P⁺
Zinc chloride	P⁺

GASES

Acetylene, dry*	E
Air, wet or dry, hot or cold*	E
Ammonia, dry*	E
Bromine	N
Carbon dioxide, wet or dry, hot or cold*	E
Chlorine, wet or elevated temps.	N
Freons*	E
Hydrogen sulfide, wet or dry, hot or cold*	E
Nitrogen, wet or dry, hot or cold*	E
Oxygen, wet or dry, hot or cold*	E
Sulfur, dioxide dry	E
Sulfur dioxide, wet	F

ORGANIC MATERIALS

Acetone, r.t.*	E
Alcohols, methyl, ethyl, etc., pure, r.t.*	E
Aniline, all concs., to 212° F.	G
Benzaldehyde, r.t.*	E
Benzene, to boiling*	E
Carbon disulfide, to boiling*	E
Carbon tetrachloride, dry, r.t.*	E
Chloroform, dry, r.t.	E
Ethyl acetate, pure, r.t.	E
Formaldehyde*	G⁺
Furfural, r.t.*	E
Gasoline, to boiling*	E

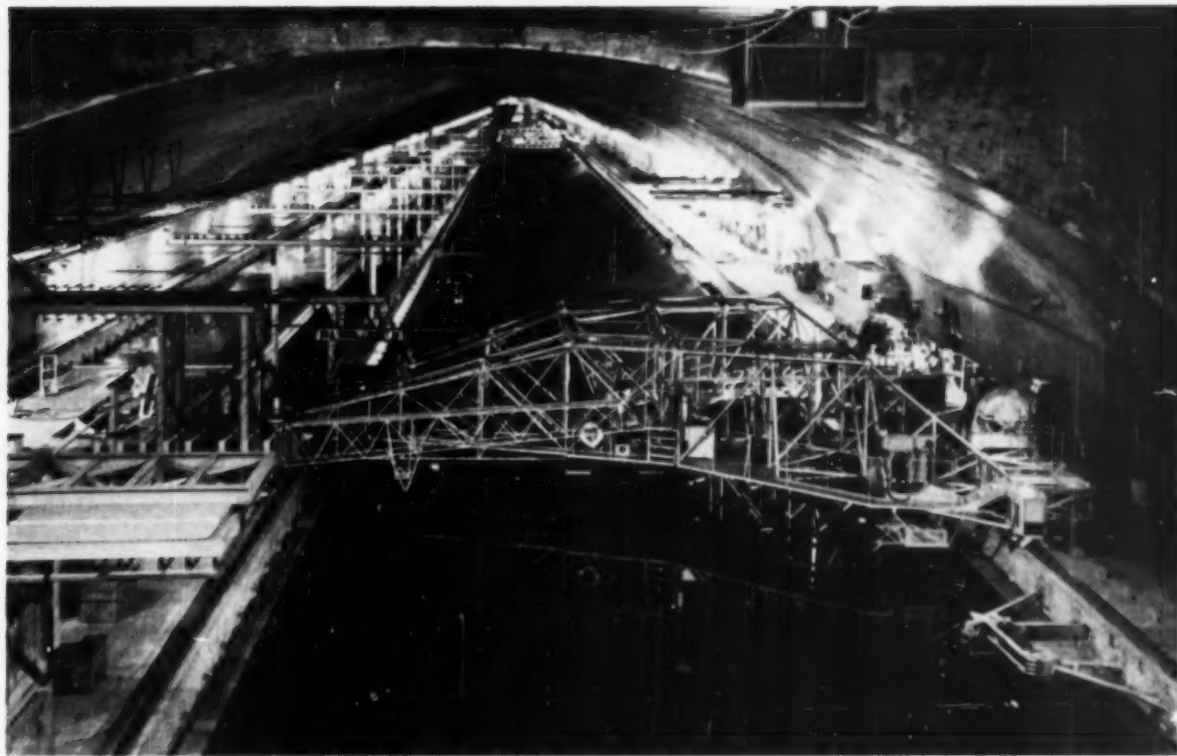**G**—Good resistance. 0.005-0.015 in./year of penetration. Satisfactory service expected; at most a slight etch.

F—Fair resistance. 0.015-0.120 in. of penetration/year. Satisfactory service under specific conditions. Light to moderate attack.

Glycerine, to boiling*	E
Glycols, ethylene and propylene, r.t.*	E
Mercaptans, amyl, r.t.*	E
Methyl ethyl ketone*	E
Oils, crude, essential, refined, vegetable*	E
Oils, sour crude (H₂S)*	E
Trichloroethylene, dry, r.t.*	E

PICKLING OPERATIONS

Acetic acid (Mag. Products)*	E
Sulfuric plus dichromate	N
Sulfuric plus hydrochloric	N

FOOD INDUSTRY

Brines, inhibited*	E
Edible oils and fats*	E
Fatty acids*	E
Fruits and fruit juices*	G
Vegetables*	G
Milk products*	E
Beer*	E

PAPER MILL APPLICATIONS

Kraft liquor	N
Black liquor	N
Green liquor	N
White liquor	F⁺
Sulfite liquor	P
Chloride bleach solution	P
Chloride bleach vapors	G
Hydrogen peroxide (above 30%)*	E
Paper makers alum*	E
Humid and chemical atmospheres*	E

PHOTOGRAPHIC INDUSTRY

Humid atmospheres*	E
Cellulose acetate*	E
Acetic anhydride*	E
Developers	P⁺
Silver nitrate	P
Solutions containing SO₂	P

FERTILIZER INDUSTRY

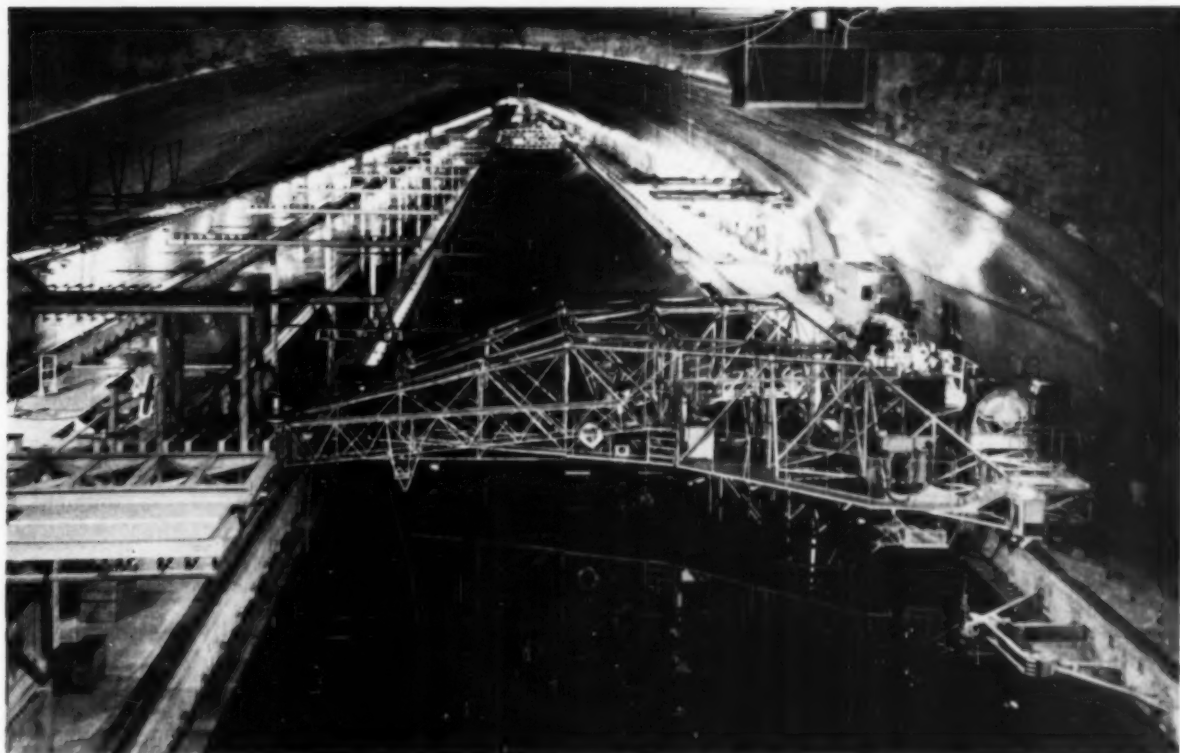|	
Ammonia, anhydrous*	E
Ammoniated ammonium nitrate*.	E
Urea*	E

* Aluminum alloys used commercially.

⁺ Subject to pitting-type corrosion.

¹ Must have trace of moisture present at boiling temperature.

² May be inhibited with sodium chromate.

P—Poor resistance. 0.120-0.420 in. of penetration/year. Satisfactory for temporary service only.

N—Aluminum not recommended. Rate of attack high.

r.t.—Room temperature.

No. 30

Interior of the basin building at the David Taylor Model Basin. This view taken from the western end of the 3/5-mile-long building shows the two principal towing tanks. The larger one is 3,078 ft. long, 51 ft. wide, and from 10 to 22 ft. deep. The high-speed tank, to the left of the trolley system, is 2,968 ft. long, 21 ft. wide, and from 10 to 16 ft. deep. The electric carriage in the center is one of four tubular-steel carriages used for towing models. Off the picture at the bottom the large tank ends in a J-shaped curve, forming a turning-test basin.

CAPITAL TIME

Story by GORDON W. McBRIDE

In early March political and legal activities in Washington will be seasoned with a bit of chemical engineering. From March 7 to 10, 1954, the American Institute of Chemical Engineers will meet at the Statler Hotel. As no technical program at any A.I.Ch.E. meeting deserves less than the three days scheduled for it, to do justice to the A.I.Ch.E. and to the Nation's capital, chemical engineers will want to come early and stay late. Here is an opportunity to see the Congress in action, to hear a case argued before the Supreme Court, to talk to scientist friends who are working in one of the departments in Washington.

Technical Program

Highlights of the technical program, under the chairmanship of George Armistead, Jr., will be symposia on atomic-energy-patents revision, presided over by W. C. Asbury; new metals technology, chaired by W. C. Schroeder; and fertilizers, headed by G. L. Bridger, as well as mixing, chaired by J. H. Rushton; liquid entrainment, under H. E. O'Connell; and chemical engineering fundamentals, chaired by R. A. Kinckiner; a good number of general papers will balance the program. Philip H. Groggins is honorary chairman of the meeting, and Randall D. Sheeline is chairman; the local program committee is headed by Arno C. Fieldner. Gordon W. McBride is chairman of public relations, Henry B. Peterson of registration, Martin T. Bennett of finance, David M. Kiefer of printing, George A. Schwabland of hotels, Al Leggin of entertainment, Arch C. Scurlock of plant trips, J. Paul Ekberg, Jr., of arrangements.

As a "special added attraction," there will be three nontechnical addresses by distinguished Washingtonians at 11:30 on each of the three mornings. Monday's speaker is the Honorable Donald A. Quarles, Assistant Secretary of Defense for Research and Development. Needless to say, he will discuss research and development in defense. On Tuesday morning the Honorable Stuart Symington, United States Senator from Missouri, will speak on tariffs, a subject of keen interest today among chemical engineering executives and sales department personnel. Senator Symington

ALUMINUM ALLOY REFERENCE SHEET

HARRY W. FRITTS — Aluminum Company of America, New Kensington, Pa.

Wrought Alloys 4S, Alclad 4S, and 50S

Commercial Products:
4S—Sheet, plate, tube, pipe.
Alclad 4S—Sheet, plate.
50S—Sheet, plate, tube.

Applications and Remarks: Alloy 4S is used where slightly more strength than 3S is desired with the same relative resistance to corrosion. Alclad 4S is used extensively for industrial building sheet because of its excellent resistance to corrosion and good mechanical properties. It is composed of a 5% coating of 72S alloy over the 4S alloy core. Alloy 50S is intermediate between 3S and 4S in strength and has about the same relative resistance to corrosion. Its principal use in the process industries is for aluminum instrument tubing. This tubing compares favorably in performance with annealed copper instrument lines and costs considerably less. These alloys are included in section 8 of the 1952 A.S.M.E. Boiler and Pressure Vessel Code.

Composition:
4S—1.2% Mn, 1.0% Mg, balance Al

ALUMINUM ALLOY

A.S.T.M. ALLOY DESIGNATIONS:
4S — MG11A
Alclad 4S — Clad MG11A
50S — G1A

A.S.T.M. SPECIFICATIONS:
B178, B209, B210, B274

MECHANICAL PROPERTIES:

	Temper Designations					
	4S and Alclad 4S			50S		
	—0	—H34	—H38	—0	—H34	—H38
Tensile strength, lb./sq.in.	26,000	34,000	40,000	21,000	28,000	32,000
Yield strength, lb./sq.in.	10,000	27,000	34,000	8,000	24,000	29,000
Elongation—% in 2 in. (1/16 in. sheet)	20	9	5	24	8	6
Shear strength, lb./sq.in.	16,000	18,000	21,000	15,000	18,000	20,000
Brinell hardness — 500 kg. load, 10 mm. ball	45	63	77	36	53	63

PHYSICAL PROPERTIES:

	4S and Alclad 4S	50S
Modulus of elasticity, lb./sq.in.	10,000,000	10,000,000
Specific gravity	2.72	2.69
Weight—lb./cu.in.	0.098	0.097
Melting range, F.	1165°-1205°	1160°-1205°
Thermal conductivity—B.t.u./(hr.)(sq.ft)(°F.)	1132 (—0)	1335 (—0)
	1132 (—H38)	1335 (—H38)
Average coefficient of thermal expansion—in./°F. x 10⁻⁶		
—76° — +68°	11.9	
68° — 212°	12.9	13.2
68° — 392°	13.4	13.8
68° — 572°	13.9	14.3
Electrical conductivity—		
% of International Annealed Copper Standard	42 (—0)	46 (—0)
	42 (—H38)	46 (—H38)

Alclad 4S—72S cladding is 1% Zn, balance Al—core is same as 4S
50S—1.4% Mg, balance Al

Formability: These alloys have good forming characteristics; however they are slightly harder to form than the comparable tempers in 3S. They can be machined using high machine speeds and high rake angle. Cutting will be slightly less stringy and weaker than 3S cuttings.

Heat Treatment: Wrought alloys 4S, Alclad 4S, and 50S are all nonheat-treatable. Their strengths are increased by cold working. The properties of the intermediate and hard tempers are stabilized by treatment at a slightly elevated temperature.

Weldability: These alloys can be welded by all the common methods. Inert gas shielded arc welding is preferred where flux removal presents a problem. Alloys 4S and Alclad 4S should be welded with alloy 4S, 43S, or A54S wire. Alloy 50S is normally welded with parent material, 43S, or A54S wire.

CORROSION RESISTANCE

ACIDS
Acetic, all concs., r.t.* E
Acetic, other than glacial, boiling E
Acetic glacial, boiling* E¹
Acetic anhydride, r.t.* E
Acrylic, glacial, r.t.* E
Benzoic, sat. soln., boiling* E
Boric, 7% soln., 180° F.* E
Butyric, all concs., r.t.* E
Butyric anhydride, r.t.* E
Carbolic (phenol), all concs., to 240° F.* E
Carbonic, all concs., r.t.* E
Chromic, below 10%, r.t. G
Cresylic (Cresol), r.t. E¹
Fatty, up to boiling* E¹
Hydrochloric, all concs. N
Hydrocyanic, all concs., r.t.* E
Hydrofluoric, anhydrous, 200° F.* N
Hydrofluoric solutions N
Lactic, anhydrous, r.t.* E
Lactic, up to 10%, r.t.* E
Maleic, 30%, r.t. E
Maleic anhydride, molten* E
Malic, to 50%, r.t. E
Naphthenic, up to 180° F.* E¹
Nitric, above 82%, to 120° F.* E
Nitric, below 82%, r.t. P
Nitric, red fuming, up to 120° F.* E
Oleic, up to boiling* G
Oxalic, all concs., r.t.* E¹
Oxalic, all concs., elevated temperature P
Phosphoric, all concs. N
Phthalic, molten E
Phthalic anhydride, molten* E
Propionic, all concs., r.t.* E
Propionic anhydride, r.t.* E
Stearic, up to boiling* E
Sulfuric, fuming G
Sulfuric, other than fuming N
Sulfurous, r.t. F
Tannic, all concs., pure, r.t.* E
Tartaric, all concs., r.t.* E

ALKALIES
Ammonium hydroxide, comm'l., r.t.* E
Calcium hydroxide, all concs. P
Potassium hydroxide, all concs. N
Sodium hydroxide, all concs. N

ALKALINE SALTS
Potassium carbonate, all concs. P
Sodium bicarbonate, all concs.* E
Sodium carbonate, all concs.* P
Sodium sulfide P

NEUTRAL SALTS
Calcium chloride, all concs., to 200° F.* G⁺²

Calcium sulfate, sat. soln., r.t.* G⁺
Calcium sulfide, all concs., r.t.* G
Magnesium chloride, all concs., r.t.* G⁺
Magnesium sulfate, to 50% soln., r.t. E
Potassium chloride, all concs., r.t. G⁺²
Potassium nitrate, all concs., r.t. E
Potassium sulfate, all concs., r.t. E
Sodium chloride, all concs., r.t.*, E G²⁺
Sodium nitrate, all concs., r.t.* E
Sodium sulfate, all concs., r.t.* E

ACID SALTS
Alum, paper makers, r.t.* E
Aluminum chloride, dry, 70° F. E
Aluminum chloride, moist P
Aluminum sulfate, r.t.* E
Ammonium chloride, all concs., r.t.* G⁺
Ammonium nitrate, all concs., to 285° F.* E
Ammonium sulfate, all concs., r.t.* E
Copper chloride, nitrate, sulfate P⁺
Ferric chloride, nitrate, sulfate P⁺
Lead chloride, nitrate, sulfate P⁺
Mercury salts N⁺
Nickel chloride, nitrate, sulfate P⁺
Silver salts P⁺
Stannous and stannic salts P⁺
Zinc chloride P⁺

GASES
Acetylene, dry* E
Air, wet or dry, hot or cold* E
Ammonia, dry* E
Bromine N
Carbon dioxide, wet or dry, hot or cold* E
Chlorine, wet or elevated temps. N
Freons* E
Hydrogen sulfide, wet or dry, hot or cold* E
Nitrogen, wet or dry, hot or cold* E
Oxygen, wet or dry, hot or cold* E
Sulfur, dioxide dry E
Sulfur dioxide, wet F

ORGANIC MATERIALS
Acetone, r.t.* E
Alcohols, methyl, ethyl, etc., pure, r.t.* E
Aniline, all concs., to 212° F. E
Benzaldehyde, r.t.* G
Benzene, to boiling* E
Carbon disulfide, to boiling* E
Carbon tetrachloride, dry, r.t.* E
Chloroform, dry, r.t.* E
Ethyl acetate, pure, r.t. E
Formaldehyde E
Furfural, r.t.* G²
Gasoline, to boiling* E

Glycerine, to boiling* E
Glycols, ethylene and propylene, r.t.* E
Mercaptans, amyl, r.t.* E
Methyl ethyl ketone* E
Oils, crude, essential, refined, vegetable* E
Oils, sour crude (H₂S)* E
Trichloroethylene, dry, r.t.* E

PICKLING OPERATIONS
Acetic acid (Mag. Products)* E
Sulfuric plus dichromate N
Sulfuric plus hydrochloric N

FOOD INDUSTRY
Brines, inhibited* E
Edible oils and fats* E
Fatty acids* E
Fruits and fruit juices* G
Vegetables* G
Milk products* E
Beer* E

PAPER MILL APPLICATIONS
Kraft liquor N
Black liquor N
Green liquor N
White liquor F*
Sulfite liquor P
Chloride bleach solution P
Chloride bleach vapors G
Hydrogen peroxide (above 30%)* E
Paper makers alum* E
Humid and chemical atmospheres* E

PHOTOGRAPHIC INDUSTRY
Humid atmospheres* E
Cellulose acetate* E
Acetic anhydride* E
Developers P⁺
Silver nitrate P⁺
Solutions containing SO₂ P

FERTILIZER INDUSTRY
Ammonia, anhydrous* E
Ammoniated ammonium nitrate* E
Urea* E

* Aluminum alloys used commercially.

⁺ Subject to pitting-type corrosion.

¹ Must have trace of moisture present at boiling temperature.

² May be inhibited with sodium chromate.

RATINGS:

E—Excellent resistance. 0.001 max. in./year of penetration. Corrosion so slight as to be harmless.

G—Good resistance. 0.001-0.015 in./year of penetration. Satisfactory service expected; at most a slight etch.

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N—Aluminum not recommended. Rate of attack high.

r.t.—Room temperature.

No. 30

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TECHNICAL PROGRAM

Monday, March 8, 1954

TECHNICAL SESSION No. 1

Mixing

9:00 A.M.—HELICAL-COIL HEAT TRANSFER IN MIXING VESSELS, J. Y. Oldshue and A. T. Gretton, Mixing Equipment Co., Rochester, N. Y.

9:30 A.M.—LIQUID EXTRACTION IN AN AGITATED VESSEL, R. H. Overcashier, H. A. Kingsley, Jr., and R. B. Olney, Shell Development Co., Emeryville, Calif.

10:00 A.M.—TIME OF A TRANSFER UNIT AND AN AGITATION NUMBER FOR BATCH OPERATIONS INVOLVING MASS TRANSFER, A. W. Hixson, T. B. Drew, and K. L. Knox, Columbia University, New York, N. Y.

10:20 A.M.—SOME PROBLEMS IN MIXING—EXPERIMENTS WITH SOLIDS, N. K. Maitra, Indian Institute of Technology, Kharagpur, West Bengal, India; to be presented by E. N. Mortenson, Swift & Co., Chicago, Ill.

10:40 A.M.—A FUNDAMENTAL STUDY OF THE MIXING OF PARTICULATE SOLIDS, S. S. Weidenbaum and C. F. Bonilla, Columbia University, New York, N. Y.

11:10 A.M. — PROGRESS REPORT OF THE A.I.Ch.E. AGITATOR TEST CODE, J. Y. Oldshue, Chairman, A.I.Ch.E. Agitators Sub-Committee; Mixing Equipment Co., Inc., Rochester, N. Y.

TECHNICAL SESSION No. 2

New Mineral-Processing Techniques

9:10 A.M.—THE PLACE OF SODIUM IN NEW METALS TECHNOLOGY, Marshall Sittig, Ethyl Corp., New York, N. Y.

9:25 A.M.—PRODUCTION OF SYNTHETIC MICA BY MEANS OF ELECTRIC MELTING, R. A. Humphrey, Mycalex Corp. of America, Clifton, N. J.

10:00 A.M. — CHEMICAL ENGINEERING ASPECTS OF TITANIUM-METAL PRODUCTION, R. L. Powell, Titanium Metals Corp. of America, New York, N. Y.

10:25 A.M.—PRODUCTION OF POWDERED COPPER, Vanston H. Ryan, Whitaker Cable Corp., Kansas City, Mo.

10:50 A.M. — VARIATIONS AND MODIFICATIONS OF THE KROLL PROCESS FOR PRODUCTION OF ZIRCONIUM METAL, H. L. Gilbert and C. Q. Morrison, U. S. Dept. of the Interior, Bureau of Mines, Albany, Ore.

NONTECHNICAL SESSION A

Technical and Patent Aspects of Industrial Atomic Power Development
2:00 to 4:00 P.M.

I. STATUS REPORT ON INDUSTRIAL ATOMIC POWER, Lawrence R. Hafstad, Director of the Reactor Division, U. S. Atomic Energy Commission.

II. DISCUSSION ON CHANGES THAT SHOULD BE MADE IN THE ATOMIC ENERGY ACT PARTICULARLY IN THE PROVISIONS REGARDING TECHNICAL INFORMATION AND PATENTS.

A. A.E.C. VIEWPOINT, G. F. Trowbridge, Office of the General Counsel, U. S. Atomic Energy Commission.

B. INDUSTRY VIEWPOINT, Edwin J. Putzell, Jr., Secretary, Monsanto Chemical Company.

C. PUBLIC VIEWPOINT, T. S. Kenyon, Chairman of the Atomic Energy Committee of the New York Patent Law Association.

D. PANEL DISCUSSION AND QUESTIONS.

TECHNICAL SESSION No. 3

New Mineral-Processing Techniques

2:00 P.M.—RECOVERY OF MANGANESE FROM STEEL-PLANT WASTE SLAGS, P. H. Royster, Mangaslag Corp., Pittston, Pa.

2:30 P.M.—THE DEVELOPMENT OF A PROCESS FOR COBALT-NICKEL-COPPER ORES, E. S. Roberts, Chemical Construction Co., New York, N. Y.

SPECIAL BUSINESS MEETING

8:00 P.M.—DISCUSSION OF PROPOSED AMENDMENTS TO THE CONSTITUTION AND NOMINATING PROCEDURES.

Tuesday, March 9, 1954

TECHNICAL SESSION No. 4

General Technical Program

9:10 A.M.—OPERATION S.P.P. (SCIENTIFIC AND PROFESSIONAL PERSONNEL IN THE ARMY), Irving Leibson and Anthony Cacoso, Biological Laboratories, Camp Detrick, Frederick, Md.

9:40 A.M.—THE CORRELATION AND PREDICTION OF THE PROPERTIES OF COMPOUNDS FROM THEIR STRUCTURE, Franc A. Landee and Victor E. Whittier, the Dow Chemical Co., Midland, Mich.

10:15 A.M.—CONTROLLING MECHANISM IN THE PRODUCTION OF NITRIC ACID BY AQUEOUS ABSORPTION OF NITROGEN OXIDES, M. S. Peters, C. P. Ross, and J. E. Klein, University of Illinois, Urbana, Ill.

10:45 A.M.—VENTURI ATOMIZATION, R. H. Wetzel and W. R. Marshall, Jr., University of Wisconsin, Madison, Wis.

TECHNICAL SESSION No. 5

Chemical Engineering Fundamentals

9:00 A.M.—USE OF THE TOTAL-PRESSURE METHOD FOR DETERMINING VAPOR-LIQUID EQUILIBRIA AT LOW PRESSURES: THE SYSTEM ANALINE-NITROBENZENE AS AN EXAMPLE, G. W. Holtzlander, J. W. Riggle, Engineering Research Lab., E. I. du Pont de Nemours & Co., Wilmington, Del.

9:35 A.M.—ESTIMATION OF VAPOR-LIQUID EQUILIBRIA FOR TERNARY SYSTEMS FROM BINARY DATA, W. H. Severns, Jr., A. Sesonske, R. H. Perry, and R. L. Pigford, University of Delaware, Newark, Del.

10:15 A.M.—GENERALIZED THEMODYNAMIC PROPERTIES OF COMPONENTS OF HYDROCARBON MIXTURES, W. C. Edmister and C. L. Ruby, California Research Corp., Richmond, Calif.

10:50 A.M.—MASS TRANSFER INSIDE DROPS FALLING THROUGH A GAS, R. R. Hughes and E. R. Gilliland, Massachusetts Institute of Technology, Cambridge, Mass.

TECHNICAL SESSION No. 6

The Use of Computing Machinery in Chemical Engineering

2:00 P.M.—THE DOW COMPUTATION LABORATORY, Franc A. Landee, The Dow Chemical Co., Midland, Mich.

2:30 P.M.—THE USE OF COMPUTERS IN KINETIC CALCULATIONS—GAS-PHASE TUBULAR-REACTOR KINETICS INVOLVING DIFFERENTIAL FOULING OF HEAT-TRANSFER SURFACE, R. E. Gee, W. H. Linton, Jr., R. E. Maier, and J. W. Raines, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

3:10 P.M.—PROGRAMMING OF KINETIC CALCULATIONS FOR AUTOMATIC COMPUTATION, J. A. Beutler, Engineering Research Lab., E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

3:50 P.M.—THE USE OF I.B.M. MACHINES IN THERMODYNAMIC COMPUTATIONS: ISOMERIZATION BETWEEN NORMAL PENTANE AND ISOPENTANE, Jack Sherman, The Texas Company, Beacon, N. Y.

4:20 P.M.—APPLICATION OF PUNCHED CARDS TO CHEMICAL PROCESS CONTROL, R. F. Stevens and J. F. Brady, National Lead Co., St. Louis, Mo.

Wednesday, March 10, 1954

TECHNICAL SESSION No. 7

General Technical Program

9:00 A.M.—MECHANISM OF RADIANT FREEZE DRYING, Robert S. Brodkey and W. R. Marshall, Jr., University of Wisconsin, Madison, Wis.

9:30 A.M.—A VERSATILE NEW MULTISTAGE EXTRACTION UNIT, Merrell R. Fenske, Pennsylvania State College, and Robert B. Long, Standard Oil Development Co., New York, N. Y.

10:00 A.M.—A LABORATORY FOR PILOT-SCALE DISTILLATION, J. E. Friden and T. G. Stack, Standard Oil Company (Indiana), Whiting, Ind.

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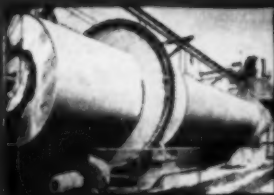
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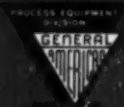
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Cutting red tape to plan a smooth meeting in Washington, D. C., March 7 to 10, 1954. Left to right: Chairmen George Armistead, Jr., technical program; Arno C. Fieldner, local program; Randall D. Sheeline, general program; Philip H. Groggins, honorary; and DeWitt O. Myatt, local section.

(Continued from page 31A)

will be remembered as former administrator of the Reconstruction Finance Corporation, former Chairman of the National Security Resources Board, first Secretary of the Air Force, and former Surplus Property Administrator.

The Wednesday morning speaker will be the Honorable Walter Williams, Under Secretary of Commerce, who will consider "Some Aspects of Economic Conditions as Related to the Chemical Industries." Mr. Williams is a graduate chemical engineer and a successful businessman.

Social Program

Sunday evening will see the meeting opened officially with a "Get Acquainted Party" in the Ballroom of the headquarters Statler Hotel. As usual, there will be no charge for admission to this function, and those who have attended the Sunday evening parties at other meetings know that the pleasure is indeed proportional to the reciprocal of the cost!

Tuesday evening has been set aside for the informal banquet, also in the Statler Ballroom. On this occasion Lewis L. Strauss, Chairman of U. S. Atomic Energy Commission, has been invited to speak.

Monday and Wednesday evenings have been left open for individual plans by the members. A number of suggestions are offered in later paragraphs for those who may wish to add something just a little different to their Washington trip.

Sightseeing being one of Washington's two major industries (politics is the other, of course), two of the most popular guided tours have been incorporated as part of the official "plant trips." Needless to add, the ladies are welcome to go sightseeing with the gentlemen on these trips.

Trip No. 1 will occupy all of Monday afternoon in visits to the interior of five of Washington's most important buildings: Bureau of Engraving and Printing, Pan American Union Building, United States Capitol, Smithsonian Institution, and National Gallery of Art. Since any one or two of these buildings would make a full day's visit worth while, there will be time for high spots only. These include a fascinating view of the printing of twenty-dollar bills and other paper money, government bonds, and postage and revenue stamps (no samples!); a glimpse through the unofficial capitol of the twenty-one republics of Central and South America, one of the most graceful structures of its kind in the world; a closer look at the workrooms of the legislative branch of our own government, including the Capitol rotunda, the House and Senate Chambers, and a view of the Congress if in session; a quick walk through a storehouse of early inventions and sentimental treasures, including for example the original "Wright Flyer," which first carried man in successful powered flight at Kitty Hawk just 50 years ago, Lindbergh's "Spirit of St. Louis," and an exhibit of all the gowns

(Continued on page 67A)

Recovery and refining units of Semet-Solvay Petrochemical Division of Allied Chemical & Dye Corp., which opened its Niagara River plant at Tonawanda, N. Y., for production of polyethylene products. The ethylene is derived from gas produced from fuel oil; polyethylene production is about 20,000,000 lb. annually. The ethylene plant was designed and constructed by The Lummus Co.

FREE CHINESE FORM CHEMICAL ENGINEERING SOCIETY

The formation of a chemical engineering society on Formosa has been reported by Thomas C. Doody, associate professor of chemical engineering at Purdue University, who is at present a member of a five-man engineering team sent to Formosa by Purdue through the Foreign Operations Administration Mission to China. The work is being directed from the university by R. Norris Shreve of the chemical engineering department. Dr. Doody is in Formosa as adviser to the department of chemical engineering of Taiwan College of Engineering.

The Chinese Institute of Chemical Engineers was organized under charter from the Nationalist Chinese government on Nov. 12, 1953, at a meeting of more than 230 chemical engineers in Kao-Hsiung (southern Formosa) during the annual meeting of the Chinese Institute of Engineers. The Institute of Engineers is composed of seven engineering societies, of which the chemical engineering group is the largest. About 1,400 members attended the two-day meeting.

Officers Chosen

At the organizational meeting of the chemical engineering group a president, eight members of the Executive Committee, and three members of the Supervisory Committee were elected. President is J. C. Huang, vice-president of the Taiwan Sugar Corp., which produced 880,000 metric tons of cane sugar last year. A graduate of the California Institute of Technology, Mr. Huang has his master's degree in chemical engineering from Massachusetts Institute of Technology. After returning to China, he became a professor of chemical engineering and later entered industry as manager of a coal distillation factory. He was formerly president of the Taiwan Alkali Co. Other officers are Fred Wong, general manager of the Kao-Hsiung Ammonium Sulphate Co.; Hua-Chou Cheng, head of the chemical engineering department of Taiwan University; Y. C. Ting, president of Taiwan Fertilizer Corp.; and K. Y. King, president of the China Petroleum Corp.

Among the papers presented at the meeting was one on the preparation of Kraft paper bags from bagasse and one entitled "A Study of Some Soil Conditioners Similar to Krilium." Dr. Doody also addressed the meeting on the organization and activities of A.I.Ch.E.

Second Chinese Society

The new institute is not the first organization of chemical engineers in China. The original Chinese Society of Chemical Engineers had at one time about 1,200 members on the mainland of China. The group was broken up when the government of Free China was forced to retire to Taiwan (Formosa), and records and membership rolls were lost.

The earlier group was founded in Boston in 1930 by a group of seven or eight Chinese chemical engineering students at Massachusetts Institute of Technology and their friends. The first annual convention was held at M.I.T. in July, 1930, and more than thirty members attended. When most of the members had returned to China by 1931, the society was moved there, and as the chemical industry developed and more technical information was needed, a journal was published by the society, which had its headquarters in Nanking.

Wartime Industry

With the Japanese invasion of China in 1937, the national capital moved inland to Chungking and the society followed. When during World War II China was cut off from the rest of the world, the construction of chemical plants was spurred, and Chinese engineers, according to the current president of the Institute, "showed great ingenuity in providing such things as petroleum products, alcohol, coke and tar, acid, and alkalies, papers, sugar, soaps and glycerine, leathers, cement and glass." More and more chemical engineers joined, and annual conventions were held until 1945. Then "some of the foremost Chinese chemical engineers," Mr. Huang stated, "withdrew from mainland China to Taiwan, and they endeavored to reconstruct Free China in the same spirit as they had built the chemical industry on the mainland. On an island which is smaller than the smallest province on the mainland they are operating bigger and better industrial plants."

MOLYBDENUM EXPANSION ANNOUNCED BY CLIMAX

Molybdenum, which was decontrolled for domestic consumption last June, was freed from export quotas last month, according to an announcement by Climax Molybdenum Co., whose daily production rate has reached 27,000 tons of molybdenum ore from its underground mine at Climax, Colo. Expansion of output has made the mine the largest underground mine in North America, second only to the Kennecott Copper Corp. Braden mine in Chile, according to company reports. The Climax ore body is the largest known primary source of molybdenum in the world and is expected to supply two thirds of the metal produced this side of the Iron Curtain. For security reasons, export licenses are still required.

Climax officials estimate that expansion requested late in 1950 by the Federal government has increased the capacity of the mine and mill 78%, from about 24,000,000 lb. in 1951 to an anticipated output in 1954 of 42,500,000 lb. The expansion was company financed.

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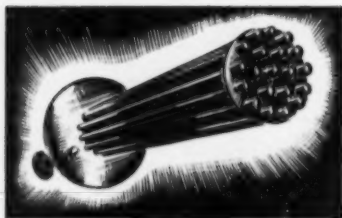
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INSTRUMENT CONGRESS PLANNED FOR 1954

Initial plans are being laid for the First International Instrument Congress and Exposition, which will be held from Sept. 13 to 24, 1954, in Philadelphia, according to Richard Rimbach, managing director.

The Exposition is sponsored by the Instrument Society of America in cooperation with the American Institute of Chemical Engineers, American Institute of Electrical Engineers, American Institute of Physics, American Microscopical Society, American Society of Mechanical Engineers, American Society of Photogrammetry, Institute of Radio Engineers, Society for Experimental Stress Analysis, Verein Deutsche Ingenieure, Deutsche Gesellschaft für Chemisches Apparatewesen.

PENN STATE TO GET NUCLEAR REACTOR

The second privately owned nuclear reactor in the U. S. will be built by Pennsylvania State University, according to a recent announcement by the Atomic Energy Commission. The first such reactor began operation last September at the University of North Carolina.

The Penn State low-power "swimming-pool" type of reactor will be constructed, at an estimated cost of $250,000 to $300,000, for nuclear research and the training of students. The reactor will operate at a power level of 100 kw., will be cooled and moderated with ordinary water, and will use enriched uranium fuel supplied by the A.E.C. The fuel elements will be suspended in a pool of water sufficiently deep to serve as a shield against the radiation produced by the reactor.

Administration of the reactor project will be under the School of Engineering, but the reactor will also be utilized for research of interest to the School of Mineral Industries, the School of Chemistry, and the School of Agriculture at the university.

PAUL G. AGNEW DIES

Paul G. Agnew, a pioneer in standardization in the United States, died on Jan. 8. He was 72 years old.

Secretary of the American Standards Association until his retirement in 1947, he served twenty-eight years in this capacity. The first recipient of the Standards Medal, an award made annually by the A.S.A., he helped to lay the foundation of the International Federation of National Standardization Associations.

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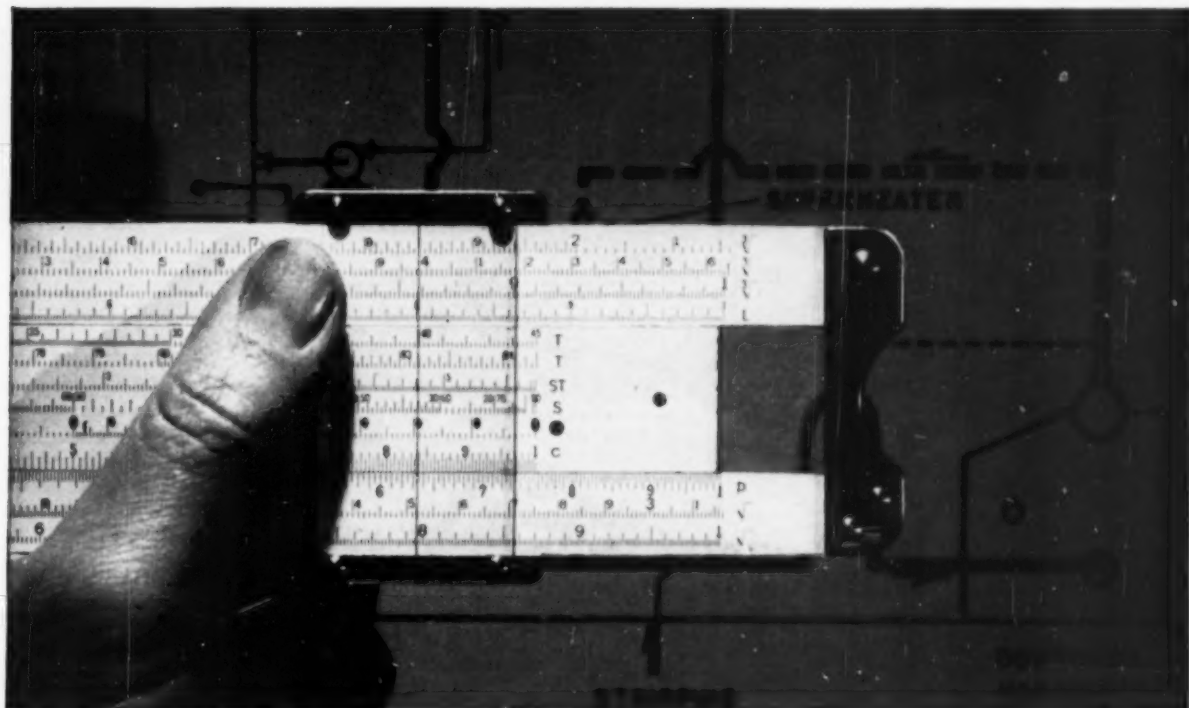
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BRAZIL WILL BE HOST TO WORLD POWER GROUP

The 1954 sectional meeting of the World Power Conference will be held in Rio de Janeiro, Brazil, from July 25 to Aug. 8, 1954. The first week will be devoted to technical sessions and the second to a rather extensive study tour by bus and airlines of various Brazilian installations.

Preprints of the papers for the meeting are expected to be distributed during May to allow time for preparation of discussion. The papers to be presented by the U. S. National Committee to the conference cover gaseous fuels, hydroelectric power, solar energy, and international water problems, including both the economical and technical aspects.

The A.I.Ch.E. is a member of the U. S. National Committee, and members of the Institute are invited to attend the conference in Rio de Janeiro, which overlaps the U.P.A.D.I. convention to be held in Sao Paulo, Brazil, from Aug. 3 to 13, 1954. Further details may be obtained from the office of the committee at 29 W. 39 St., New York 18, N. Y.

CHEMICO WILL RUN CALERA'S COBALT PLANT

Using chemical techniques rather than conventional smelting and refining methods, the Chemical Construction Corp. will manage and operate a new cobalt refining plant at Garfield, Utah, for the Calera Mining Co., a subsidiary of Howe Sound Co. The contract will run for two years.

A. E. C. PLANS NEW SYNCHROTRON

Construction of a $20,000,000 ultra-high-energy particle accelerator will be started soon at Brookhaven National Laboratory, Upton, N. Y. The new machine, an alternating gradient synchrotron, will be designed to produce beams of protons of energies ranging up to 25 billion electron volts.

The energy of the particle beams produced by accelerators bears a direct relationship to the nulcear phenomena that can be studied. As higher energy levels have been attained in laboratory machines, new subnuclear particles have been discovered and new nuclear phenomena observed. The most powerful accelerator now in operation is the Brookhaven Cosmotron, which has accelerated protons to energies of 2.3 billion electron volts. The Bevatron, under construction at the University of California Radiation Laboratory at Berkeley, will accelerate particles into the 5- to 7-billion-electron-volt range.

C. G. Kirkbride (left), President of Houdry Process Corporation and of A.I.Ch.E., congratulates Eugene J. Houdry, founder of the company, on receiving the John Scott Medal Award from Ernest T. Trigg (right), vice-president of the Board of City Trusts of Philadelphia. The Scott Medal for scientific and technological achievement was awarded to Mr. Houdry for his inventions in the catalytic cracking of petroleum.

A.S.E.E. Reports Plans for Raising Standards

"The leaders of the engineering profession twenty-five years hence must be engineers who are at no loss in interpreting or themselves contributing to the extension of the fields of engineering science." This philosophy dominates the preliminary report of the Committee on Evaluation of Engineering Education of the American Society for Engineering Education, a committee appointed "to determine the pattern or patterns that engineering education should take to provide the leadership that the profession must have twenty-five years from now."

Believing that the many research physicists who have had to concentrate on nuclear problems will not return to other fields, the Committee finds that research in all phases of the engineering sciences—vibration, elasticity, plasticity, heat transfer, engineering thermodynamics, fluid flow, and others—is now the responsibility of engineers.

A number of the recommendations and conclusions concerning science requirements are of interest to chemical engineers. The Committee considers mathematics through ordinary differential equations close to a minimum requirement for all engineers, recommends increased emphasis on advanced chemistry courses and on nuclear and solid-state physics, and names nine important background sciences in engineering—statics; dynamics; strength of materials; fluid flow; thermodynamics; electrical circuits, fields, and electronics;

heat transfer; engineering materials; and physical metallurgy. Design or analysis leading to design is recommended as an integrated study for four successive semesters.

In recognition of the importance of social studies and the humanities, the Committee asserts that they should enrich student lives; "provide inspiration for seeking greater knowledge and understanding"; and "aid the student to develop judgment and discrimination, a sense of value, and a sound personal philosophy." These studies should "trace the political, economic and social history of mankind to give students a clearer perspective of our civilization today." The Committee warns against emphasis on immediate usefulness in these fields at the expense of the more valuable broader objectives.

Improving the scientific background of engineering faculties and keeping within each faculty "a balance of experience in both the science and the art of engineering" are other suggestions. The Committee emphasizes the need for teachers who conduct superior engineering or educational research and publish work of good quality; who engage in consulting work at a creative level; who exercise leadership in scientific, educational, and professional societies; or preferably who combine such activities. The basis of the recommendation is the philosophy that superior teachers develop superior students.

A bifurcation in engineering education is visualized in the report, the branches being *professional-general* and *professional-scientific* education.

The first is designed to train engineers to serve in the areas 1) between engineering and business, management, law, real estate, or agriculture; 2) between engineering and a branch of science with limited opportunity for applying engineering analysis and design; and 3) between engineering and a highly applied technology like production processes, operation, construction, air conditioning, welding, or wood technology. The program for professional-general education would have seven of the nine sciences; reduced requirements in mathematics, physics, and chemistry; and only two continuous semesters of engineering analysis and design.

The acceptance of a curriculum as engineering education, however, "is to be made wholly upon its content of the engineering sciences and the use made thereof in the study of engineering analysis, design and engineering systems." Liberal acceptance of experimental programs that include a satisfactory content of engineering science and applications of it to engineering analysis and design is recommended. To avoid unduly restricting the number of accredited curricula, the Committee has approved a special designation for any curriculum "taught by a faculty of unusual distinction where the program conducted by the faculty is of such a nature as to develop in a considerable proportion of the graduates a capacity for creative technical activity or creative leadership in engineering."

The suggestions on accreditation were presented to stimulate discussion and analysis. Comments should be addressed to Professor Dan Pletta, secretary of the Committee on Evaluation, Virginia Polytechnic Institute, Blacksburg, Va.

FORUM URGES RELAXING OF ATOMIC ENERGY ACT

The Atomic Industrial Forum, Inc., has added its voice to the call for relaxation of government control of atomic energy. In a discussion on the meaning of the Congressional hearings on atomic energy, recently issued as a Forum Report, an eight-man panel headed by E. Blythe Stason, dean of the Michigan University law school and chairman of the special committee on atomic energy of the American Bar Association, declared that "to permit private enterprise to participate in atomic energy development on a risk basis, the present government monopoly should be relaxed by revision of the Atomic Energy Act."

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28A Honeywell Instrumentation
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Chemical Engineering Progress

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Remember, the numbers on the upper portion of the card bring you data on only the bulletins, equipment, services, and chemicals reported in these information insert pages. The lower portion of the card is for the advertised products, and is keyed not only to advertising pages, but also to the memory-tickling list under the heading Products.

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Louisville Drying Machinery Unit, General American Transportation Corp.

34AL   **Yorkmesh Demister**
For mist separation in vacuum towers.
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35A   **Pressure or Vacuum Filtration**
Features an Eimco precoating unit.
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A metal for most acid solutions and corrosive gases or vapors except HF, alkali, or substances containing free SO_3.
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40AL Uscolite Valves
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41A Continuous Calciner and Cooler
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The C. O. Bartlett & Snow Co.

43A Stainless Products
Stainless castings, valves, fittings and accessories.
The Cooper Alloy Foundry Co.

44A Control Valves
Automatic control valve illustrated.
Hammel-Dahl Co.

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Features 10-cu.ft. capacity production blender with intensifier bar. Available in sizes 1- to 75-cu.ft. working capacity.
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Haveg Corp.

58AL Paracoil Heat Exchangers
Special equipment, pilot plant units or plant modernization programs.
Davis Engineering Corp.

59A Sump Pumps
Single unit and duplex applications. Bulletin.
Johnston Pump Co.

61A Fintube Tank Heaters
Vertical mounting on legs 12 in. above the tank bottom prevents any deposits from settling on the heating surface. Bulletin.
Brown Fintube Co.

63A Temperature Difference Controller
Measures volatile content of stripper bottoms to within 0.02%. Regulates flow of sparging steam or column input to maintain proper balance.
The Foxboro Co.

64AT Pyrogen and Bacterial Retentive Filters
Unit available for either double or single filtration Lucite construction.
Ertel Engineering Corp.

64AB Plug Valves
Valves for almost everything piped.
DeZurik Shower Co.

65A Zipper Conveyor
Conveyor zips shut after loading, forms a moving tube.
Stephens-Adamson Mfg. Co.

66AL Wire Cloth
Made of all malleable metals. Meshes, ranging from 4 in. space cloth, up to 400 mesh.
Newark Wire Cloth Co.

67AR Acid Storage Tanks
Construction may include steel, Knight-Ware, Permanite, rubber, lead, glass, or carbon. Also chlorinators, drying towers, scrubbers, etc.
Maurice A. Knight

68AT Variable Speed Pulleys
Available in 8 sizes—fractional to 8 hp. with ratios to 3 to 1.
Lovejoy Flexible Coupling Co.

68AB Proportioning Pumps
7,500, 15,000 or 30,000 lb./sq.in. working pressure by the interchange of piston and cylinder assemblies. Bulletins.
American Instrument Co., Inc.

69AR Teflon Yarn Lattice Braid Packing
For service against the most destructive and corrosive acids on pump shafts and valve stems.
The Garlock Packing Co.

70AL Antifoam
3 grams kill foam in 10 tons of asphalt or alkyd resin. Free sample.
Dow Corning Corp.

71AR Valves
Made of corrosion-resisting alloys combined with a Teflon sleeve.
The Duriron Co., Inc.

73AR Teflon Products
Extruded or molded rods, tubes, and special shapes. Stress relieved or high tensile sheets and moldings. Precision machined components and filled products.
Ethylene Chemical Corp.

74AT Furane Resin Cement
Mortar for corrosion-resistant masonry, supplied in the form of powder and liquid, for mixing at time of use. Folder.
Delrac Corp.

74AB Conductivity Bridge
For electrolytic conductivity measurements of purest distilled water to highly conductive acids. Also widely used for electrical conductivity measurements and tests.
Industrial Instruments, Inc.

75AR Technical Molybdenum Trioxide
The raw material for the production of all molybdenum compounds.
Climax Molybdenum Co.

77AT Vitreous Silica Laboratory Ware
Superior chemical purity and unusual resistance to heat shock.
The Thermal Syndicate, Ltd.

PRODUCTS (Continued)

77AB   **Special Filtering Problems**
Packaged plant for continuous filtration of molten phosphorus. Also standard filtering problems. Bulletin.
R. P. Adams Co., Inc.

78AL   **Thickeners and Clarifiers**
Beam-type units and center-column units. Thickeners automatically lift the scraper away from the overload.
Hardinge Co., Inc.

79AT   **Process Piping**
Fabricated from complete range of alloys, any diameter up to 60 in., and in any shape.
The Pressed Steel Co.

79AB   **Spraco Nozzles**
Full cone, flat spray and hollow cone spray nozzles. Catalog.
Spray Engineering Co.

82AL   **Varidrive Motors**
Any r.p.m. by dial control. Ratios up to 10:1. ¼ to 50 hp., 2 to 10,000 r.p.m.
U. S. Electrical Motors, Inc.

82AR   **Color Comparators**
For determinations of pH, chlorine, phosphate, as well as complete water analysis.
W. A. Taylor and Co.

83AT   **Hydrostatic Gauges**
For pressure, vacuum, draft depth and absolute, barometric, and differential pressure. Bulletins.
Uehling Instrument Co.

83AB   **Evactors**
Steam jet vacuum units provide pressures ranging from a few inches to a few microns.
Croll-Reynolds Co., Inc.

IBC   **Engineering Service**
Process comparisons and cost surveys, process designs, etc.
The Vulcan Copper & Supply Co.

OBC   **Mixers**
Supplied in the exact power-speed-torque combination needed.
Mixing Equipment Co., Inc.

EQUIPMENT

1   **Chlorinators.** Simple, high capacity chlorinators with wide operational range, dependable for municipal & industrial chlorination from Fischer & Porter Co. Called Figure 1052 Ratachlor, units handle to 6,000 lb./day with manual or automatic proportioning.

2   **Lab Blender.** Patterson-Kelley Co., Inc. pint-size twin-shell lab blender. Smaller than current 4-qt. size, new yoke model has two small blenders in yoke capable of being interchangeably mounted in 4- & 8-qt. frame. Lucite blades in load capacities of 1, 2, & 4 pints. Dust & water tight, easily opened cover plates for cleaning.

3   **Stainless Steel Valve.** For service in the food, chemical, & related industries, stainless steel valves from Cooper Alloy Foundry Co. Available in ½-, ¾-, & 1-in. sizes. Dirt & corrosion resistant.

4   **Laboratory Mixes.** Young Machinery Co. new laboratory mixer with capacity of 0.34 cu.ft.; steam jacketed for 15 lb./sq.in.; stainless with carbon steel jacket; available with floor or table stand, two types of motors. For chemical, food, allied industries.

5   **Floating Roll Mill.** Three new roll mills from Charles Ross & Son, Co. offer ease in proper setting of rolls. Operable by unskilled labor. Sizes from 4½ × 10 in. to 16 × 40 in. Prevention of uneven wear on rolls reduces maintenance costs.

6   **Viscosity Measurement.** From Foxboro Co. technical report on system for accurate measurement of viscosity under industrial conditions. Helpful in understanding & applying rotational viscometer in control of product quality. Diagrams & text describe viscometer, operating principle, construction details.

7   **Tray Belt Filter.** Folder describing dewatering filter from Hardinge Co., Inc., called tray belt filter. Bulletin includes complete operating details, discusses applications & advantages over other types. For continuous liquid-solids separation in chemical, mining, industrial fields.

8   **Pressure Reaction Apparatus.** Parr Instrument Co. shaker-type pressure apparatus for catalytic reduction & other reactions with hydrogen; constant volume, variable pressures 1 to 5 atm., temperature to 100° C.

9   **Filter.** In-line filters for use with highly corrosive materials, fuming nitric acid, hydrogen peroxide, hydrochloric acid, etc. Porous Plastic Filter Co. porous Kel-F medium. Large surface area; no catalyzed decomposition of hydrogen peroxide.

10   **Dissolver.** Designed to speed up dissolving, dispersing & mixing operations is a new bottom drive ultrafast dissolver. Motor mounted beneath unit; shaft enters through bottom of tank eliminating aeration of materials during processing & permitting easy pressurizing of tank. Blends polyethylene & wax. Wide range of tank capacities. Cowles Co., Inc.

11   **Gas-Analysis Apparatus Kit** by Fisher Scientific Co. Permits any desired assembly of large variety of units from standardized interchangeable parts. For gas trains Fisher-Reeder pipette can triple gas analyzer's work output. Solenoid-driven pump injects four jets of absorbent chemical into pipette's gas-filled chamber 24 times/min.; thoroughly & quickly intermixes liquid & gas.

12   **Dynel Work Clothing.** New type heavy duty work cloth of 25% Dynel 75% processed wool reduces cost of garments for working under conditions requiring protection from heat or cold. From 10% to 15% stronger than all-wool of same weight. Chem-Wear, Inc.

14   **Dust Collectors.** Available in two new models for removal of nuisance & toxic dusts. Housed in circular case 5 ft. high & 2 ft. in diam.; capacity 400 cu.ft./min. Dust is collected on outside of filter tubes providing filter area of 60 sq.ft. Operates under vacuum preventing dust leakage. Folder. Wallace & Tiernan.

15   **Nylon Texstar.** Nonwoven fabric for industrial uses. High tear strength, easily stitched, washable, equally strong wet or dry. Suggested for gaskets, filters, etc. Star Woolen Co.

16 **Sectionalized Cylinder.** Cylinder sectionalized in three pieces with inlet & discharge valves in fronthead & backhead. Cylinder-liners equipped as standard. Easily disassembled; liner removed without disconnecting piping. Permits better cooling; provides lower temperature throughout. Available in single stage; 100 lb./sq.in. gauge rating. Pennsylvania Pump and Compressor Co.

17 **Fume Hoods.** Feature improved design & construction with parabolic cutout which increases passage of air from room into hood plenum chamber proportionally as sash is lowered. Results in constant speed of air drawn across working surface regardless of hood sash position. A. B. Stanley Co.

18 **Low-Temperature Chamber.** Line of subarctic low-temperature industrial chambers in five sizes, covering most industrial needs. Work spaces 1 to 12 cu.ft. Use Freon refrigerants; operate at −40 to −170° F. Equipped with Tenney compressors. Tenney Engineering, Inc.

19 **Rotary Feeder Air Lock.** For handling bulk material under high pressure or vacuum in the chemical- & food-processing industries, rotary feeder air lock available in cast iron, stainless steel, or Monel from Beaumont Birch Co. Seal may be spring loaded, of neoprene, rawhide, asbestos, or Teflon, run dry or lubricated as required. Rotor has six pockets or more, vanes are hard surfaced.

20 **Air Sampler.** Inexpensive, dependable radioactive dust air-sampler for use with any laboratory vacuum system. Stainless steel filter holder, vacuum gauge, vacuum hose attachment. Designed for 22-mm. filter paper; can be mounted on standard Tracerlab 1-in. planchet for counting. Tracerlab, Inc.

21 **Magnetic Pump.** Fostoria Pressed Steel Corp. Dynapump circulator. Said to be quiet, with no shaft seal or motor bearing requiring service. Light weight, for heads to 24 ft. For radiant baseboard heating, adaptable for many other uses. Wetted parts of stainless steel. Interchangeable flanges ¾ to 1½ in.

22 **Weather-Ometer.** Features positive control of specimen temperatures for increase in test accuracy. Automatic humidity control optional. Radiation from two Atlas enclosed carbon arcs. Atlas Electric Devices Co.

23 **Synchronizing Contactor.** For precisely coordinating electric circuits with mechanical systems. Coordinates angular position of rotating shaft with opening or closing of electric circuit. Switching is by set of automotive distributor points actuated, once each revolution, of hardened, polished steel cam on drive shaft. Cams for opening or closing circuits. Handles 1 amp. at 125 v.a.c. Farmer Electric Co.

24 **Calculator.** Revised coal tar base pipe-enamel calculator. Estimates quantities of enamel required in lb./1000 ft. & gal./mile based on two grades of primer. Estimates coupling compounds required for mechanical couplings on normal pipes 2- to 48-in. diam. Reilly Tar & Chemical Corp.

25 **Lithium Ores.** Added to American Potash & Chemical Corp. lithium products are lepidolite & petalite ores. For use in manufacture of glass & ceramics, & other applications.

26 **Three-Tube Relay.** Ebert Electronics Co. model HR-17 for heavy amperage control applications. Each tube can control to 60 amp. at 115 v.a-c; 35 amp. at 230 v.a-c. d-c control 12 amp. at 115 v. Coils for variety of voltages.

27 **Miniature Potentiometer.** Brochure from Bourne Laboratories describes miniature gauge pressure potentiometer in ranges from 0 to 100 & 0 to 5,000 lb./sq.in. Diagrams, curves, charts, outline drawings provide technical information. Specifications include linearity, hysteresis, resolution, etc.

28 **Exhaust Silencers.** Two new series of silencers for reducing noise made by air compressors, blowers, vacuum pumps & other machines expelling high velocity air to atmosphere. Burgess–Manning Co. For operation under moisture-free air conditions & temperature to 200° F. Pipe sizes to 6 in. in CA series; larger than 6 in. in LCA series.

29 **Nema Motors.** Designed to operate under most outdoor plane conditions. Totally enclosed & fan cooled, built to provide full protection to all parts. Also suited to indoor installations where moist, dirty, or corrosive atmospheres exist. Dust tight bearings, cast iron cooling fan, one-piece aluminum fan. Belgian Electric Sales Corp.

30 **Relief Valves.** Automatic functioning, high capacity. For safety & relief of wide-range liquids & vapors. Adapted by change of external actuating equipment. Available in 2, 3, 4, & 6 in. sizes for pressures 3 oz./sq.in. to 150 lb./sq.in. Controlled Flow Valve Co.

31 **Annunciator System.** Automatically pinpoints trouble by indicating off-normal variable. Used where alarms are supplied to closely interrelated variables. Panalarm Products, Inc.

32 **High Capacity Blower.** With 6-in. wheel, for speedy removal of fumes, smoke, stale air, or for cooling & ventilating. Moves to 600 cu.ft./air (min.). Automatic cutout prevents overheating of completely enclosed 100-v. 60-cycle motor. Standard Electric Mfg. Co., Inc.

33 **Industrial Wiping Tissues.** Improved Kimwipes, Industrial tissues for all wiping, cleaning, polishing jobs. Non-abrasive, cannot mar or scratch any surface. Available in 15 x 18 in. size or 5 x 9 in. Kimberly-Clark Corp.

34 **Liquid-Level Indicator Systems.** Model SL-101 uses ultrasonic pulse ranging technique. No moving parts, accurately indicates to within 0.01 ft. true liquid levels in petroleum, chemical, pharmaceutical, processing & storage tanks. Bogue Electric Mfg. Co.

35 **Packaged Filter Unit.** Has all dewatering elements located in one base, using small floor space & headroom. Wet vacuum pump eliminates moisture trap with extensive overhead piping. Dimensions are 5 ft. 8 in. wide by 9 ft. 10 in. and height 7 ft. 10 in. Five discs normally used. Each additional disc increases length of unit by 14 in. Denver Equipment Co.

36 **Laboratory Centrifuge.** Multipurpose laboratory centrifuge features small size & weight & power requirements; stainless steel internal parts, simple operation, is easily maintained. Speeds to 12,000 rev./min.; centrifugal force 7,500 gravities or more. Capacity 1/5 to 2 gal./min. Merco Centrifugal Co.

37 **Cartridge Demineralizer.** Brochure describes late model permanent cartridge demineralizer with laboratory stand. Shows operating diagram. Makes high purity water easily available. Maintained by replacement of Pennex resin charge. Penfield Mfg. Co., Inc.

38 **Small Instrument Air Valves.** Newly added to line of Crawford Fitting Co. Equipped with Swagelok ends to provide torque-free seals on all installations. Arrow embossed on valve body shows direction of flow. Brass, aluminum, steel & stainless steel.

CHEMICALS

60 Check List. Metal protective & paint-bonding chemicals & processes. A handy, quick reference guide for metal preservation needs. American Chemical Paint Co.

61 Kel-F Buyers Guide. A 16-page guide which permits ready selection of specialties in molding & fabricating products of Kel-F, ranging from blown bottles & insulated filters to insulated wiring. Section on corrosion control, and other pertinent information. M. W. Kellogg Co.

62 Sodium Dispersions. A 30-page booklet on sodium dispersions, their properties, industrial applications. Includes preparation techniques, gives diagrams of equipment, much other data. U. S. Industrial Chemicals Co.

63 Cellosolve Acetate. New technical bulletin gives physical, chemical & physiological properties; resin solubilities; performance data, etc. Carbide and Carbon Chemicals Co.

64 Glycerine. The versatility of glycerine in commercial formulations discussed in bulletin from Glycerine Producers' Assoc. Discusses six properties & how they have been used. Explains formulator's problem in each case.

65 Resin Cement. Furane resin cement, Resiment, for acid brick or tile mortar in corrosion-resistant tank linings, floors, sewers, towers, etc. Low porosity, high compressive & tensile strength, resistant to impact & abrasion. Delrac Corp.

66 Silicon Carbide. A 52-page brochure on silicon carbide, its applications, manufacturing techniques & details of all pertinent information. Extensive bibliography included. Carborundum Co.

67 Renewable Water Repellents. Arccopels DC-2 & DC-3. technical data sheet lists properties, uses, & other information. American Resinous Chemicals Corp.

68 Basic Coatings. Three basic coatings for plastic materials. One for application on fabricated articles of Styrene, Royalite, Acrylic & some acetates; second, for application molded Polystyrene; third for metallizing of plastic decorating. All may be pigmented or dyed any color tone. Color cards available. Developed by Sullivan Chemicals Division of Sullivan Varnish Co.

69 Organic Sequestrants. Now available to industry are Perma Kleers, the stable salts of polyamine carboxylic acids distinguished from EDTA by excellent solubility, superior chelation of ferric ion & efficiency for sequestering calcium and divalent metals. Refined Products Corp.

70 Phenolic Resins. Line of phenolic resins based on R-108 chemistry with outstanding chemical resistance to protective coatings, introduced by Chemical Division of General Electric Co. Wide range of compatibility with resins used in finishing field. Uses include container linings for drums, cans, pails, etc.

71 Aritemp Resins. Casting resins for encapsulation & embedment of electronic components & circuit assemblies. Excellent adhesion to metals & other plastics. Low-moisture absorption & vapor transmission. Bulletin. Aries Laboratories, Inc.

72 Reagents. Two new reagents—N^1, N^1-diethylsulfanilamide & m-toloxyacetic acid are among group of ten new compounds added to line of Distillation Products Industries. Abstracts of procedures for use of both chemicals available.

73 Waste Treatment Chemicals. B-I-F Industries, Inc. 16-page technical bulletin contains pertinent data & information interesting to design engineers and supervisors of operations of water, sewage or waste treatment plants where chemicals are used in treatment processes. Includes information on fifty chemicals used in water purification, sewage, waste treatment; other data.

74 Paint Selector. For aid in selection of proper paint for each application & elimination of guesswork or need for experiment. Easy to use file-size reference chart. Applications include machinery, linoleum, stucco, canvas. Tropical Paint and Oil Co.

75 Plasticizers. Two low-temperature plasticizers for polyvinyl chloride resins now available in commercial quanties. Di-n-octyl, n-decyl phthalate (DNODP) and Di (2-ethylhexyl) adipate (DOA). DOA imparts excellent low-temperature flexibility, heat & light stability. Monsanto Chemical Co.

76 Antioxidant. A food-grade antioxidant for use by renderers known as Tenox R is combination of food grade Tenox BHA (butylated hydroxyanisole) citric acid & propylene glycol. Liquid form facilitates easy measuring & insures good solubility of new product in fat itself. Eastman Chemical Products, Inc.

77 Acetate Sheeting & Film. Four-page folder discusses principal markets for Celanese acetate sheeting & film as guide to the trade. Table of properties included. Celanese Corporation of America.

78 Synthetic Detergent. Antara Chemicals Division of General Dyestuff Corp. announces production of a 26% active slurry form of Igepon made from tallow. First tallow-based synthetic detergent. Technical data & samples available.

79 Synthetic Flowable Rubber. Free-flowing synthetic rubber known as DPR Synthetic N-27 reactive intermediate. Considered new raw material for plasticizing or modifying of plastics & synthetic resins. H. V. Hardman Co.

80 Platinum Metals Catalysts. Booklet gives notes on their uses & a list of their most commonly available forms, also other pertinent data. Baker & Co., Inc.

81 Chemical Intermediates. Five new chemical intermediates from production of allethrin now available from U. S. Industrial Chemicals Co. Division of National Distillers Products Corp. Chemicals believed to have possible use for synthesis of pharmaceuticals, perfumes, fungicides, insecticides, & other fine chemicals.

82 Polymerization Catalyst. Experimental quantities of phenylcyclohexyl hydroperoxide for use as an activator for GR-S cold rubber formulations, now available. Product is a yellowish liquid containing 20% hydroperoxide. May also be good as polymerization catalyst for applications such as styrenated polyesters. Monsanto Chemical Co.

83 Versen-OL. New product having wide application in wet processing wherever trace iron creates problem & contamination results. The trisodium salt of N-hydroxylethylethylene diamine triacetic acid, a compound extremely soluble in water. High stability through pH range. Bersworth Chemical Co.

BULLETINS

90 Fluidized Feeder. For use in either reaction processes or materials handling, new fluidized feeder permits feed of fluidized beds of granular or powdered solids in dense phase through pipes. Equipment aids conversion of noncontinuous processes to continuous. Feeds solids into vessels pressurized to 700 lb./sq.in. Sawyer Bailey Corp.

91 (91) Oil-immersed starters for low-voltage motors for use
92 in corrosive or hazardous gas locations provide adequate motor protection, easy maintenance. Descriptive bulletin. (92) Hand pyrometer measures temperature of any solid surface, liquid, gas or molten metal from 0 to 1,500° F. Illustrated folder. General Electric Co.

93 Automatic Control Equipment. Illustrated loose-leaf catalog includes tables, data sheets, all pertinent information. Hammel-Dahl Co.

94 Engineering & Construction Services. The recent activities of a major firm serving the petroleum, chemical & petrochemical fields are the subject of an illustrated brochure. Contains photos, descriptive material on many plants, catalytic-cracking units & compressor stations. Fluor Corp., Ltd.

95 Tank Car Classifications. Booklet published as a service to shippers of bulk commodities entitled "Tank Car Classifications." Includes types of tank cars approved for variety of specific commodities. Compiled in accordance with all current regulations. American Car and Foundry Co.

96 Demineralization Handbook. "Handbook on Demineralizing" explains principles of ion exchange, applications of many anion & cation exchange materials. Series of curves aid in estimating operating cost. Flow diagrams, data on design & operation of systems, etc. included. Cochrane Corp.

97 Permanent Magnets. Brochure for use by process engineers, and others in the selection of equipment to safeguard costly machinery & material in process. Outlines importance of magnetic protection in industrial processing operations. Prater Pulverizer Co.

98 Differential Pressure Transmitters. Bulletin on autronic differential pressure transmitters describes type D2T transmitter in detail, with principles of operation. Illustrated with hookup and schematic diagrams, dimensional diagrams. Swartwout Co.

99 Plastic Pipe. Catalog on plastic pipe describes principal types made, shows how to join plastic pipe, lists engineering & corrosion data, gives uses. Republic Steel Corp.

100 Spectrograph. Said to be the first commercially available spectrograph with plane grating. Gives higher resolution & dispersion with wider coverage. Rapid & easy to operate. Data folder. Jarrell-Ash Co.

101 Polyethylene Liner. Cylindrical liners for use in shipping & storage of liquid and bulk products in quantities 15 gal. or more. Made from tubular film of thicknesses to 6 mils with bottom to fit circular or square containers. Insures 100% product recovery, protects against contamination. Diaphane Corp.

102 Dehydrating Equipment. Illustrated catalog on rotary continuous dehydrating press equipment. Covers various types in detail, shows diagrams, lists tables, other engineering data. Davenport Machine and Foundry Co.

103 Optical Pyrometer. Bulletin on self-contained, direct reading, accurate optical pyrometer said to be rugged, foolproof & dependable. Lists principles of optical pyrometry, operating procedure, maintenance. Pyrometer Instrument Co., Inc.

104 Boiler Water Sample. Bulletin illustrating the Paracoil sample cooler. Maintains specified boiler water treatment, checks effectiveness of blowdown procedure, determines amount of dissolved oxygen. Listed are features, use of charts, instructions for installation & operation. Davis Engineering Corp.

105 Austenitic Stainless Steels. Booklet on corrosion-resisting properties of the austenitic chromium-nickel stainless steels. Tables show test results in various solutions, acid, neutral & alkaline. Other valuable information. International Nickel Co., Inc.

106 (106) Bulletin on multipoint recorder-controller. Design
107 features illustrated. Exclusive Turret pen permits six individual records on single chart. (107) Fielden Tektolog & the Null Balance Recorder are said to be capable of gathering data from 24 separate sources & logging collective information on single circular chart. Both provide accurate measurement for vast range of industrial process & laboratory applications. Fielden Instrument Division, Robertshaw-Fulton Controls Co.

108 Pneumatic Thermometer Controller. A moderate cost instrument is described and illustrated in bulletin. Shows applications & features, lists specifications, other data. Minneapolis-Honeywell Regulator Co.

109 Controlled Volume Pumps. Bulletin on air-powered controlled volume pumps. Contains graphic presentation of pump operating principles; capacity-pressure & air-consumption tables; examples of chemical feed systems using these pumps. Milton Roy Co.

110 Chemical Porcelain. An 8-page bulletin illustrating & describing chemical porcelain. Includes check valves, plug valves, swivel joints & many other items. Lists sizes, other information. U. S. Stoneware Co.

111 Ion Exchange. Bulletin entitled "Amberlite Ion Exchange," describes fundamental processes of ion exchange, history of synthetic resin ion exchange, development, etc. Also gives information on regeneration. Application section covers 13 process types. Rohm & Haas Co.

112 Titanium. (112) Booklet on Rem-Cru titanium & titanium
114 alloys. Gives history, names properties, gives comparison with other materials, etc. (114) Resistance to corrosion issue of the Rem-Cru Titanium Review devoted to all phases of subject. Rem-Cru Titanium, Inc.

115 Stainless Steel Tubing. Seamless, welded stainless steel tubes illustrated & described in bulletin. For use in process industries applications where corrosion, scaling, or insufficient strength under heat is a major factor. Lists sizes, standard tolerances, workability chart. Globe Steel Tubes Co.

116 Adjustable V-Belt. TD & TE adjustable V-belt reduces installation & operation costs on larger drives. Catalog fully illustrated gives operation characteristics, tells how to couple or uncouple & install. Mannheim Mfg. & Belting Co.

NEWS

CHILTON CONTINUES AS HEAD OF E.M.C.

Thomas H. Chilton, technical director, engineering department, Du Pont Co., and former president of A.I.Ch.E., will continue as chairman of the Engineering Manpower Commission of Engineers Joint Council for 1954, according to a recent announcement. Other officers of the commission will be M. M. Boring, manager of technical personnel division, General Electric Co., who will be vice-chairman, and T. A. Marshall, Jr., who will retain his position as executive secretary.

In accepting the chairmanship Dr. Chilton announced that E.M.C. and the Scientific Manpower Commission, established by eight national professional societies, would cooperate closely during 1954. "A primary aim of both organizations," Dr. Chilton said, "will be to function as catalyzers and to carry on and coordinate activities to the end that the recruitment, training, and utilization of scientists and engineers will be seen as an integrated sequence of responsibilities with which the professional societies, industry, education, government, and the public are all vitally concerned."

CHEMICAL MARKET RESEARCH TO MEET

Electrochemicals and their derivatives will be the topic of the Chemical Market Research meeting at the Hotel Niagara, Niagara Falls, N. Y., on Feb. 25, 1954. Papers will discuss the chemical industry of Niagara Falls, calcium carbide and acetylene, carbon tetrachloride and perchlorethylene, peroxides, chlorates, sodium, caustic potash, caustic soda, chlorine, hydrochloric acid, the chemical industry and the tariff. The banquet speaker will be Gen. Clinton F. Robinson, president, Carborundum Company.

CANADIAN ENGINEERS MEET IN MARCH

The Chemical Engineering Division of the Chemical Institute of Canada will hold a conference at the Sheraton-Mount Royal Hotel on March 1 and 2. The conference will be cosponsored by the Petroleum Group of the Institute's Montreal Section, and papers presented by both Canadian and U. S. engineers will largely concern the petroleum field. Plant visits will be to the Shell Oil Petrochemical Plant and Refinery and to Distillers Corp., Ltd.

Sir Douglas Copland, high commissioner for the Commonwealth of Australia in Canada, will speak.

Washington Meeting Schedules Discussion on Constitutional Changes

Changes in Institute membership grades and privileges, the subject of lengthy Council debate and consideration, are now ready for submission to the membership. After informal discussion at the business meeting held in St. Louis, Council at its January fifteenth meeting decided to invite member reaction at the special business meeting called for the Washington national meeting, to be held at the Statler Hotel, Monday, March eighth, at 8:00 p.m. After member comment at the meeting, the proposals, in accordance with Article IX of the constitution, will then be sent to the Active members "with a letter ballot, together with a copy of any recommendations that Council may care to make." C. G. Kirkbride, president of the Institute, will be in the chair.

Essentially two proposals will be discussed at the Washington session.

The first proposal has two parts. Part one is a change in the present membership titles, Active, Junior, and Associate member. Active members would be known as Members; the present Junior and Associate grades would be combined in one grade to be known as Associate member; and a third and new grade would be provided under the name Affiliate. The change in the title from Active member to Member does not contemplate any change in the requirements for this—the full professional—grade. The proposed changes also would do away with the requirement that those reaching the age of thirty-five must transfer from Junior membership into either Active or Associate membership. The second part of the first proposal provides that the new Associate grade, which would embrace the present grades of Junior and Associate member, would carry the privilege of nominating and voting for officers and directors, but these members would be unable to hold office or vote on amendments to the constitution.

The new grade of Affiliate would require only that a man "be engaged in an activity and possess scientific attainments or actual experience which qualify him to cooperate with engineers in the advancement of chemical engineering knowledge and practice." This, essentially, is the requirement for the present grade of Associate member under Section 3d.

As was brought out by T. H. Chilton, chairman of the Constitution and By-Laws Committee of the Institute, at the St. Louis meeting, the proposed changes bring the Institute in line with nomenclature prevailing in or being adopted by the major engineering societies, and these grades are in conformity with the recommendations made by the Committee on Professional Recognition of the Engineers' Council for Professional Development.

The present Student grade of membership will remain as is.

The second proposal would establish a nominating-committee procedure instead of a ballot mailed annually to Active members so they may nominate officers and directors. As advanced in Council, the purpose behind this is to provide a more orderly method of assuring the candidacy of members qualified and willing to serve. The nominating-committee procedure, however, makes provision for Members and Associate members (new nomenclature) to place on the ballot names of candidates willing to serve. The Members and Associate members might nominate any Member by obtaining fifty signatures and filing the nominating petition with the secretary not later than nine weeks prior to the annual meeting. The nominating committee would then prepare an election ballot containing the names of nominees for president, vice-president, secretary, treasurer, and directors. Under this procedure it is felt that the present system of local sections' suggesting candidates would not be precluded and at the same time the Institute would at all times be guaranteed the nomination of a slate of officers able to serve.

At the St. Louis meeting, during the business session T. H. Chilton called for a voice vote on the new proposals, and those attending the session indicated practically unanimously that they were in accord with the suggestion that voting rights be given to Junior and Associate members.

The suggestion of changing the titles of membership grades from Junior and Associate to Associate member received some opposition, but this came mostly from Junior members who saw no reason for the change to be made, feeling that no stigma attached to the title *Junior* and failing to see any real advantage in the change. As explained by Chilton, one of the chief advantages is uniformity with other engineering societies. As stated at the business meeting, the term *active member* is difficult for other groups to understand and in time the use of Member with a capital *M* will signify the full professional grade in most engineering societies.

At present the secretary's office is mailing the proposals to amend the constitution to all Active members of the Institute, the format showing the present constitution in one column and the proposed amendment in the second column. Should Junior or Associate members require copies, the office is prepared to fill such requests.

In commenting on the forthcoming discussion, T. H. Chilton states that "while adoption of amendments is by mail ballot of the Active members, it is hoped that all attending the Washington meeting will come prepared to express their views on these proposals and that others will feel free to communicate in writing with the president or the secretary, views of the Junior members on those provisions affecting their status being especially desired."

Members of Council are eager to convey to the membership that the changes as proposed bear their full accord and recommendation. They wish to point out especially that the requirements for Member (previously Active member) have not been changed and that the standards of the Institute are in nowise compromised.

As provided in the constitution, after the Washington discussion the secretary will mail to each Active member a copy of the amendment or amendments proposed for adoption and a letter ballot, the votes to be returned to him in not less than sixty days or more than seventy days after date of mailing. The count of the vote will be made by two tellers appointed by Council.

To carry the amendments at least twenty per cent of the present Active members have to vote and at least three quarters of all votes received must be in favor of the changes.

ANNUAL REPORT OF COUNCIL

1953

This is the annual report, covering the actions of the Council of the Institute during the period Nov. 1, 1952 to Dec. 1, 1953. During this period there were seven meetings of the Council and twelve meetings of the Executive Committee to attend to matters which must be handled each month by the Executive Committee; the business of five of these meetings was handled by means of a mail ballot. This report, therefore, is a summary of the actions of the Council and Executive Committee as monthly reports appear in *Chemical Engineering Progress.*

Treasurer

The resignation of C. R. DeLong as Treasurer, effective July 1, was accepted by the Council with much regret. He was replaced, in accordance with the conditions of the Constitution, by G. G. Brown.

Membership

It is gratifying to report that the rate of increase in Institute membership has continued again this year about the same as for the last several years. The total membership as of Nov. 1, 1952 was 12,405, and as of Dec. 1, 1953 was 13,539, thus making an increase of 1,134 of which 414 were Active, 218 were Associate and 502 were Junior members. The accompanying table analyzes this membership increment in detail.

One point which should receive special comment is the acceptance by those Junior members who reached the age of 35 of the privilege of automatic transfer to Associate membership. There were 271 which represents 72% of the total number (377) of Junior members whose Junior membership otherwise would have expired and application would have been necessary for continuation of membership. This is the highest percentage since the amendment to the By-Laws making this privilege possible. In addition forty such Juniors were elected to Active membership, thus making a net loss in membership from Juniors in this category of only 66 or 17%.

Publications

CEP has continued to be the official publication of the Institute. The number of papers has increased appreciably over the period covered by the preceding report and also circulation and advertising. Supplemental publications have been continued and the Series now consists of six Symposium Series papers and one Monograph Series publication.

Publications of The Institution of Chemical Engineers (London) have been available to Institute members at a special price. This is the first full year in which their publications have appeared as quarterly issues. There has been a slight increase in the interest in these publications.

Meetings

Four meetings were held during the period of this report: The annual meeting was held in Cleveland, Ohio, Dec. 7-10, 1952; the first national meeting in 1953 was held at Biloxi, Miss., March 8-11; the second national meeting in 1953 was held in Toronto, Canada, April 26-29; the third national meeting in 1953 was held at San Francisco, Calif., Sept. 13-16. The attendance at these meetings was gratifying and while not setting records was significant in number.

Constitution and By-Laws

The Council, during the period of this report, amended the By-Laws to make provision for the establishment of divisions. The first division thus authorized is the Nuclear Engineering Division which will sponsor a meeting in Ann Arbor, Mich,. June 20 through 25, 1954.

A slight modification in the By-Laws provides for a change in committee structure of the Institute as it affects publications. The Publications Board, which has been functioning since the initiation of *CEP*, has been discontinued and its activities have been transferred to the Publication Committee.

Membership	Active	Associate	Junior	Total
Nov. 1, 1952	4,704	669	7,032	12,405
Elections	502	237	858	1,597
Deceased	31	1	6	38
Resigned	32	7	154	193
Dropped	22	11	148	181
Elections rescinded	3	...	48	51
Dec. 1, 1953	5,118	887	7,534	13,539

	Nov. 1, 1952		Dec. 1, 1953		13 Months 1952-1953 Increase	
Membership	No.	%	No.	%	No.	%
Active	4,704	37.9	5,118	37.8	414	8.8
Associate	669	5.4	887	6.6	218	32.6
Junior	7,032	56.7	7,534	55.6	502	7.1
Total	12,405	100	13,539	100	1,134	9.1

REPORT OF COUNCIL

At several meetings of the Council the question of amending the Constitution to change the grades of membership as well as the requirements for membership has been discussed at length. Council is not in a position to make definite recommendations to the membership regarding amendments at this time but this subject will be continued as an active one during 1954.

Accrediting

The Chemical Engineering Education and Accrediting Committee has had another active year with the review and reinspection of a large number of curricula with the thought of bringing our accrediting activities in line with those of the Engineers' Council for Professional Development. The Council has accredited or continued accreditation and recommended similar action to E.C.P.D. of thirty-six curricula in chemical engineering. The Council is pleased to report that the E.C.P.D. has taken the same action so the two lists of accredited curricula in chemical engineering continue to be the same.

Research Committee

A special research program on the subject of "Plate Efficiencies in Fractionating Columns," which was announced a year ago, has gotten under way and periodic progress reports have been issued by the Research Committee. The work for the current year is being carried on at the University of Michigan, University of Delaware, and North Carolina State College. Work is no longer being carried on at the Polytechnic Institute of Brooklyn, which was one of the original schools participating in this program.

Awards

Upon recommendation of the Awards Committee, the Council approved the following awards which were made at the annual meeting in Cleveland in December, 1952: The William H. Walker Award went to J. H. Rushton in recognition of his publication record over the years in the fields of equipment design, mechanical mixing, and engineering education, and for his recent contributions to *CEP*. The Junior Member Award was made jointly to Thomas Baron and Lloyd G. Alexander for their paper, "Momentum, Mass and Heat Transfer in Free Jets," published in *CEP*, **47**, No. 4. The Professional Progress Award in Chemical Engineering went to Richard H. Wilhelm for his distinguished contributions to the theories and experimental data of fluid mechanics, mass and heat transfer, and reaction rates, and for his special applications of these theories to fluidized solid systems and to biochemical and textile processing. This award is administered by the Institute and sponsored by the Celanese Corporation of America.

In addition to the above awards there are the prizes given in connection with the Student Problem Contest. The First Prize, the A. McLaren White Award, went to Harold Hublein of Cooper Union, second prize to Rodney A. Nelson of the University of Minnesota, and the third prize to David G. Stephan of Ohio State University; honorable mention to: Joseph H. Jaffer, Jr., of Yale University, Robert H. Schwaar of the University of Illinois,

and Eugene Motte of the University of California.

The program which was started some years ago was continued throughout this year namely, the recognition of excellence of presentation of papers at meetings of the Institute. The following were the recipients of this award now generally known as the Presentation Award: F. M. Tiller (Cleveland meeting), Arthur B. Metzner (Biloxi meeting), Richard E. Emmert (Toronto meeting) and David W. Schroeder (San Francisco meeting).

Student Chapters

Council has approved the establishment of a student chapter at Louisiana Polytechnic Institute, thus bringing the total of student chapters to ninety-nine.

The Student Chapter News has continued publication and is serving a useful purpose in bringing news of the Institute to the members of student chapters. J. G. Knudsen of Oregon State College has been its editor.

Wherever the student chapters are so located geographically that it is practical to hold regional meetings, this practice has been continued, the number participating varying from five to eight student chapters. Eight such meetings were held. These meetings are recognized by the Council through the awarding of cash prizes, certificates, and subscriptions to *CEP* to those students who are judged by a special committee to have presented the best paper at the meeting.

There has been a continuation of the recognition of scholarship through the Scholarship Award. This recognition consists of a certificate, subscription to *CEP*, Student Membership and a Student Pin, awarded to that member of a student chapter who has attained the highest scholastic standing in his freshman and sophomore years in a curriculum leading to a degree in chemical engineering.

Institute Sections

Upon the recommendation of the Institute Sections Committee the Council has approved the establishment of the Tidewater Virginia Section. In the period prior to the authorization of the establishment of an Institute section the group functions as a Chemical Engineers Club and there are at this time thirteen such groups carrying on an active program.

Housing

The growth of the Institute and the expansion of its activities have made the Council conscious of the possible need for a different type of housing from what has been used in the past. The Institute always maintained space in commercial buildings and the alternative to this is to acquire and operate headquarters owned by the Institute. A committee was appointed consisting of E. P. Stevenson (chairman), R. P. Kite, G. G. Brown, F. J. Van Antwerpen and S. L. Tyler to study and report. Several properties were inspected but no definite recommendations as to the acquisition of any of them was made. This committee has been in close touch with the United Engineering Trustees, who operate the Engineering Societies Building at 29 West 39th St., New York City, and who are investigating the possibilities of a new Engineering Center in which this Institute would be included with several others. An exploratory survey has been made to determine the best method of

financing either the acquisition of property in the name of the Institute or in cooperating with the other societies in the establishment of a national Engineering Center. This study is continuing and it is possible that action may be taken within the next year.

Questionnaire

The questionnaire sent out by the Public Relations Committee early this year has been of great help to Council in its deliberations as indicating the opinions of the membership. Reports of analyses of this questionnaire have appeared in *CEP*.

Cooperation with Other Groups

The Institute through representation has continued to cooperate with many other groups; among these should be mentioned American Society of Mechanical Engineers, American Society for Engineering Education, American Association for the Advancement of Science, in which Institute membership status has changed from that of Associate member to Affiliate member with two representatives now on its Council, American Standards Association, Electrochemical Society, Engineers' Council for Professional Development, Engineers Joint Council, National Association of Corrosion Engineers, National Research Council, National Safety Council, U. S. National Committee of the World Power Conference, U. S. National Committee on Theoretical and Applied Mechanics. Special mention should be made of the activities of the Air Pollution Control Committee of the A.S.M.E., the Chemical Industry Advisory Board of A.S.A., as well as its special committees on Letter Symbols and Abbreviations for Science and Engineering; also Graphical Symbols and Abbreviations for Use on Drawings. New representation this year has been on the Chemical Resistant Materials Committee of the Electrochemical Society Corrosion Handbook. The Education Committee and the Committee on Professional Training of E.C.P.D. have been quite active during the year. Through our cooperation with E.J.C., Institute representation has been active on its Engineering Manpower Commission, Special Surveys Committee, and the Committee on International Relations in cooperation with the National Science Foundation in the problem of preparing a Register of Scientific and Specialized Personnel.

It is with regret and a deep feeling of real loss to the Institute that the Council reports the death of the following members during the year:

Active Members: Charles C. Ahlum, David Guy Anderson, Jr., Emil C. Barell, Luis H. Bartlett, H. V. Berg, Ernest H. Chapin, LaVerne E. Cheyney, Richard A. Crawford, Gaston DuBois, T. V. Fowler, Laverne T. Heaps, Carl Victor Herrman, Otto Bernard May, Harry McCormack, J. S. Miller, Harley J. Morrison, Ralph E. Myers, J. P. C. Peter, C. F. Ritchie, W. B. Shanley, George W. Smith, P. Arvard Smith, Jr., Walter E. Smith, R. King Stone, J. A. Struthers, Selah S. Tomkins, L. D. Vorce, Alfred H. White, William M. Whitten, Jr., and James R. Withrow.

Associate Member: F. I. Gibson

Junior Members: Robert E. Drummond, Mahlon T. Dunbar, L. J. Harlow, Raymond J. Lakey, D. F. Rynning and Albert E. Weinhardt.

MARGINAL NOTES

Registration—A Guarantee

Engineering Registration, Nathan W. Dougherty, The University of Tennessee Press, Knoxville, Tenn. (1951), 78 pp. $1.00.

Reviewed by Henri J. Molaison, U. S. Southern Regional Lab., New Orleans, La.

Prominence of the author (who has held the office of chairman of the Tennessee State Board of Architectural and Engineering Examiners) in the field of engineering registration is in itself a strong recommendation for reading this volume. The work covers not only the subject of Registration, but also the story of united efforts in the engineering profession; and Dean Dougherty believes that the registration movement itself is part of the larger movement of professional recognition and unity.

After years of notable achievement in design and construction, engineers wanted to be recognized as professionals; but they found that education and experience had made them specialists rather than group-conscious engineers, that they were organized for fragmentation instead of for unity, and that solidarity of the profession was imperative for achievement of professional recognition.

In the discussion on unified efforts of the engineering societies the author brings out the weakness of federation (e. g., the late American Engineering Council) as compared to a unity society of individual membership where failure of the organization in the latter case is less likely when a few turn away. However, major effort at unified action of the societies has nevertheless been through their federations which showed, and still show today (e. g., E. J. C. and E. C. P. D.), how educators and practicing engineers have become conscious of professional need, and have done something about it.

Wyoming and Louisiana passed laws before the national engineering societies took notice. In general the societies first opposed registration, then became lukewarm, and finally became convinced of its rightful place in the activities of their members. A.I.Ch.E. members will be interested in the author's mention that the American Institute of Chemical Engineers, at its first official considera-

tion of registration in 1922, decided to oppose all registration laws for engineers; but that the Institute's opposition later dwindled progressively to the point where it cooperated with the other engineering societies and the National Council of State Boards in revising the Model Law. The road taken by many other technical engineering societies was largely the same. Even A.S.C.E., which has the longest record (since 1900) of sustained interest, blew hot and cold on the subject until state groups of civil engineers organized to have their legislatures pass the first laws.

Books Received

Experiments, Theory, and Problems in General Chemistry—An Integrated Course. Hosmer W. Stone and James D. McCullough, McGraw-Hill Book Co., Inc., New York (1953), viii + 352 pp. $6.00.

Elementary Quantitative Analysis. Ralph L. Van Peursem and Homer C. Imes, McGraw-Hill Book Co., Inc. (1953), xiii + 383 pp. $4.50.

Modern Electroplating. Edited by Allen G. Gray. John Wiley & Sons, Inc., New York (1953), xii + 563 pp. $8.50.

Biochemical Preparations—Vol. 3. Esmond E. Snell, Edior in Chief. John Wiley & Sons, Inc., New York (1953), viii + 128 pp. $3.50.

Protective Atmospheres. A. G. Hotchkiss and H. M. Webber, John Wiley & Sons, Inc., New York (1953), viii + 341 pp. $7.00.

Imidazole and Its Derivatives—Part I. Klaus Hofmann, Interscience Publishers, Inc., New York (1953), xviii +447 pp. $13.50.

Methods for Emission Spectrochemical Analysis. American Society for Testing Materials, Philadelphia 3, Pa. (1953), vii + 309 pp. $5.15 (clothbound) and $4.50 (paper cover).

Organic Syntheses—An Annual Publication of Satisfactory Methods for the Preparation of Organic Chemicals. C. C. Price, Editor in Chief. Vol. 33. John Wiley & Sons, Inc., New York (1953), vi + 115 pp. $3.50.

The author agrees: That registration in itself does not make a competent practitioner but is a guarantee that he has had training and experience in the field; also that it is not an easy matter to measure ability in the various engineering fields, with range of activity so wide and personal qualities so important that no single measure can be found. He gives a sample list of seventeen reasons used by opponents of the registration movement over the years; does not undertake to answer each immediately, but draws his conclusions in favor of registration at the end.

Enforcement of the present laws is the greatest improvement that can come to registration, and only action of the profession itself can effect this. Included in the book is an explanation why regulation by state statutes is better than delegation of such authority to guild or profession, or to universities. Contrasting attitudes of union and profession are taken up.

"It took forty years for the beginnings in Wyoming to spill over into Montana and make the roll of states complete." Yet, this was the equivalent of the advancement by law and medicine in centuries of trial-and-error growth. The author believes that registration will result in a better public understanding of engineers. He stresses that engineers deserve public understanding and esteem, and recognition as professionals, and that the legal status given by registration laws is part of the great movement to give them that rightful public recognition and make them conscious of their professional status. The increasing impact of engineering on other professions makes it essential that engineers be legally defined. Registration has more possibilities than mere certification, and if the registrants are fully qualified, engineering can approach the profession visioned by its idealists. "Only a unified and activated profession, as a whole, can keep its ranks free from the shyster and the charlatan and add prestige to its good name."

The book is a succession of significant statements of high professional value—every one of which should be of extreme interest to every engineer, who considers himself in a profession which is increasing at an ever higher rate its already important contribution to our civilization and standard of living.

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee or Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before March 15, 1954, at the Office of the Secretary, A.I.Ch.E., 120 East 41st Street, New York 17, N. Y.

Applicants for Active Membership

Alexander, Roy E., Louisville, Ky.

Beverly, Elton R., North Boston, N. Y.

Blasewitz, A. G., Richland, Wash.

Bretton, Randolph H., New Haven, Conn.

Brown, Peter F., Montchanin, Del.

Boyd, Austen W., Schenectady, N. Y.

Carpenter, John H., Englewood, Colo.

Charbonnet, Wilfred H., Lyndhurst, Ohio

Cooperman, James, Chicago, Ill.

Crim, Thomas, Jr., Augusta, Ga.

Dawson, George L., Jr., Rochester, N. Y.

Dayton, Herbert P., Baytown, Tex.

Fahnoe, Frederick, Morristown, N. J.

Feerick, Aubrey A., El Dorado, Ark.

Frick, Louis T., Niagara Falls, N. Y.

Fry, Homer W., Coraopolis, Pa.

Frye, Clifton, Tulsa, Okla.

Fuente, Herbert A., Chicago, Ill.

Geitz, Robert, Demarest, N. J.

Grandey, Loren F., Long Beach, Calif.

Haile, Benjamin C., Jr., Los Angeles, Calif.

Hill, John H., Texas City, Tex.

Hodgkinson, Raymond E., Houston, Tex.

Holby, George V., Huntingdon Valley, Pa.

Hollowell, E. Graham, Easton, Pa.

Hudson, William G., Westfield, N. J.

Jungerman, George R., Allen Park, Mich.

Killgore, J. Barker, Baton Rouge, La.

Larson, Marvin W., Cleveland, Ohio

Leonard, Milton H., Akron, Ohio

Mackenzie, K. G., New York, N. Y.

Mathy, E. V., Bartlesville, Okla.

Mitchell, Richard J., Pleasant Hill, Calif.

Peddicord, Haskell J., Cincinnati, Ohio

Pence, Henry E., New Brighton, Pa.

Pontius, Eugene C., Chester, Va.

Powell, Robert L., Nixon, N. J.

Presnell, J. H., Pasadena, Tex.

Reynolds, Edward H., Wilmington, Calif.

Reynolds, Wilmer, Jr., Louisville, Ky.

Rezny, Robert E., Whiting, Ind.

Scalzo, Joseph R., Toledo, Ohio

Shaffer, John H., Painesville, Ohio

Skaar, Karsten S., China Lake, Calif.

Stevens, Roger G., Lafayette, La.

Streitmatter, L. O., Homewood, Ill.

Swartz, Dorman J., Buffalo, N. Y.

Swartz, George B., Jr., Pittsburgh, Pa.

Taggart, Ganson P., Cambridge, Mass.

Tallman, John C., Wilmington, Del.

Vignale, Vito J., Roselle, N. J.

Webb, Albert O., Cuyahoga Falls, Ohio

Applicants for Associate Membership

Ullmann, F. D., Oakland, Calif.

Whitt, Carlton D., Decatur, Ala.

Applicants for Junior Membership

Andresen, Art W., Ames, Iowa

Aung, U. Htun, Rangoon, Burma

Bagnoli, Eno, Wilmington, Del.

Baker, Roy A., Houston, Tex.

Baumeister, Ernest B., Kellogg, Idaho

Bierbower, Robert G., Claymont, Del.

Blanc, Louis F., Charleston, W. Va.

Bradley, Robert S., Beaumont, Tex.

Braunstein, David, New York, N. Y.

Brown, Robert O., Pasadena, Tex.

Bryan, Robert J., Alhambra, Calif.

Bullington, Louis A., Baytown, Tex.

Hopper bottom car discharges to ZIPPER in shallow tunnel. After short, horizontal run, the ZIPPER rises vertically to 35' to clear buildings.
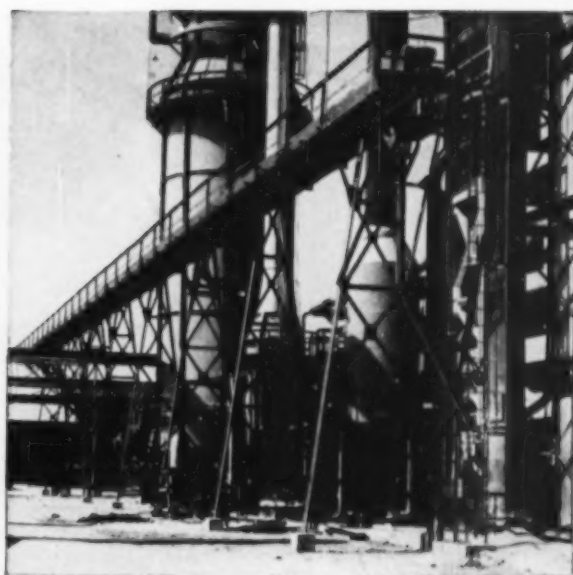
ZIPPER runs overhead 250 feet to discharge point. With a belt speed of 106 feet per minute, the conveyor can handle 10 tons per hour.

ZIPPER CONVEYOR CARRIES CATALYST
"Up-and-Over" Without Degradation

How to move bead catalyst from dump cars to a bucket elevator lifting to storage gave a tough problem to plant engineers at this Oil Company in Louisiana.

They couldn't use a conventional belt conveyor at ground level because of intervening buildings. To tunnel underground meant cutting through foundations and relocating pipe lines. The simplest way was to go overhead. But with conventional equipment this meant big power requirements and excessive degradation that would destroy much of the effectiveness of the catalyst.

The company's engineers came up with a smooth-working solution. They found that a single S-A ZIPPER Conveyor could follow the overhead route easily, using only light structural supports. But more important, because this remarkable conveyor *zips shut* after loading, it forms a snug, moving tube in which the bead catalyst cannot shift. *Degradation is practically non-existent*—and a 5 HP motor with Saco Speed Reducer provides all the power needed.

If you have a bulk materials handling problem that seems hard to solve, why not let our engineers look it over? Write us for a free survey.

Open Zipper Conveyor Belt rounds tail pulley and moves to loading point. Side walls then zip shut to form a snug fitting tube around the material.

STEPHENS-ADAMSON MFG. CO.

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Engineering Division
Specialists in the design and manufacture of all types of bulk materials conveying systems.

Standard Products Division
A complete line of conveyor accessories including centrifugal loaders — car pullers — bin level controls—etc.

SealMaster Division
A complete line of industrial ball bearing units available in both standard and special housings.

WASHINGTON MEETING

worn by the first ladies at the inauguration of their husbands as presidents of the United States; and finally a tantalizingly short look at some of the world's finest art treasures in one of the most beautiful of art galleries.

Trip No. 4, the other sightseeing trip, is scheduled for an early Tuesday morning start. Although the interior of some of the buildings will be visited, it also includes about 35 miles of leisurely driving through Arlington and Alexandria, Va., to Mount Vernon. Lunch will be served before the return to the Statler at 1:30 p.m. This tour goes through an old section of Washington, then past the Lincoln Memorial, and across the Potomac River via Memorial Bridge. In Arlington Cemetery are seen Lee Mansion and the grave of General Pershing, and a stop is made at the Memorial Amphitheater and the Tomb of the Unknown Soldier. Leaving Arlington, the tour journeys to the historic city of Alexandria, America's oldest incorporated town and the hometown of General Washington. Christ Church, Carlyle House, Ledbetter's Apothecary, Gadsby's Tavern, Wyse Tavern, the old firehouse, and other interesting buildings will be visited. Then continuing along the Potomac River, over beautiful Memorial Highway, the tour reaches Mt. Vernon. Here there will be ample time to visit this famous home and the tomb of George and Martha Washington. The return trip will include a lunch stop at The Old Club Tea House in Alexandria and a view of National Airport, the Pentagon Building, Jefferson Memorial, and the Tidal Basin.

Ladies' Program

Aside from the sightseeing trips and the Sunday and Tuesday evening programs described in the preceding section, the ladies' time has been left free for shopping (style shows are a regular feature at some of the hotels and department stores at lunch time), bridge, or informal sightseeing. Also, tickets will be available for visits to some of the local broadcasting studios. Mrs. Walter J. Murphy, Chairman of the Ladies' Committee, and her coworkers will be on hand to assist in arranging impromptu excursions and entertainment.

Why Come to Washington?

Professionally, A.I.Ch.E. meetings should pay big dividends to all who attend. Getting into new surroundings four times a year, even if he should see only "the same people every time," does something to stimulate the chemical

engineer. Plan now to get the jump on Mother Nature and beat the cherry blossoms to the Tidal Basin!

Socially, Washington is a pleasant place to visit. There are interesting places to see, interesting things to do, and interesting foods to eat. The whole family may want to be at the Washington meeting.

Of special interest, the White House has recently been rebuilt (an engineering feat of no small size), and visitors may see some of the first-floor rooms between 10 o'clock and noon on Saturday morning. No visitors are permitted on Sunday and Monday mornings, and there are formally scheduled Institute events on Tuesday and Wednesday, so engineers who don't come early enough to see the White House on Saturday morning will have their next best chance on Thursday or Friday after the meeting.

The Capitol and The Library of Congress are open to visitors every day, but normally the House and Senate would not be in session on week ends. Sessions may be checked by newspapers or telephone. As the Supreme Court is open every day but Sunday, a trip to Capitol Hill on Saturday afternoon would be worth while in any case. And across the street is the Folger Library of Shakespeariana. It too is worth a couple of hours on Saturday afternoon.

Tip for the Gourmets

When evening comes, dinner plans may be aided by the variety of restaurants in Washington, which is particularly strong in seafood and French restaurants but offers also a wide variety of other types, including Italian, German, and steak and chop houses.

As a matter of fact, the best food in Washington is served in the various embassies, but for anyone who can't wangle an invitation to an embassy dinner, Ray Ewell offers the following suggestions: the Colony, La Salle du Bois, or Maxime for French food; Hammel's for wiener schnitzel and good draught beer in a gemütlich atmosphere; real Italian food at Rocco's; Jewish specialties at the Roumanian Inn; the Madrillon for arroz con pollo, shish kebab, and other exotic delicacies; the Syrian New Bagdad; and such well-known steak, chop, and seafood houses as Fan and Bill's, Hall's, Harvey's, Occidental, Parchey's or good American cooking at Ted Lewis's or the Palladian Room of the Shoreham Hotel.

Those who want to go to one of Washington's theaters, including one of the country's best theaters-in-the-round (the Arena Stage), however, should start early so as not to rush the meal.

10:25 A.M.—ANALYTICAL METHODS FOR BATCH FRACTIONATION, A. I. Johnson, Chen-Jung Huang, F. D. F. Talbot, University of Toronto, Ontario, Canada.

10:55 A.M.—CORRELATION OF THE NUMBER OF THEORETICAL PLATES VS. REFLUX RATIO, G. I. Parisi and Joseph Joffe, Newark College of Engineering, Newark, N. J.

TECHNICAL SESSION NO. 8

Chemical Engineering in the Fertilizer Industry

9:10 A.M.—TRENDS IN THE FERTILIZER INDUSTRY, Edwin C. Kapusta, National Fertilizer Association, Inc., Washington, D. C.

9:50 A.M.—A CONTINUOUS AMMONIATOR FOR SUPERPHOSPHATES AND FERTILIZER MIXTURES, L. D. Yates, F. T. Nielsson, and G. C. Hicks, Tennessee Valley Authority, Wilson Dam, Ala.

10:30 A.M.—A CONTINUOUS PROCESS FOR PRODUCTION OF HIGH-ANALYSIS GRANULAR MIXED FERTILIZERS OF HIGH AMMONIUM NITRATE CONTENT, S. J. Martenet, E. Rauh and Sons Fertilizer Co., Indianapolis, Ind.

TECHNICAL SESSION No. 9

Liquid Entrainment and Its Control

2:00 P.M.—THE PROBLEM OF LIQUID ENTRAINMENT, Sanford C. Reynolds, Metal Textile Corp., Roselle, N. J.

2:15 P.M.—ENTRAINMENT FROM BUBBLE-CAP TRAYS, D. J. Simkin, C. P. Strand, and R. B. Olney, Shell Development Co., Emeryville, Calif.

2:50 P.M.—THE OCCURRENCE AND CONTROL OF RADIOACTIVE ENTRAINMENT IN EVAPORATIVE SYSTEMS, B. Manowitz, R. H. Bretton, and R. V. Horrigan, Brookhaven National Laboratory, Upton, N. Y.

3:25 P.M.—ENTRAINMENT REMOVAL BY A WIRE-MESH BLANKET AND THE MECHANISM OF ITS OPERATION, C. LeRoy Carpenter and Donald F. Othmer, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

4:00 P.M.—PERFORMANCE OF WIRE-MESH DEMISTERS, Otto H. York, Otto H. York Co., Inc., East Orange, N. J.

TECHNICAL SESSION 10

Chemical Engineering in the Fertilizer Industry

2:00 P.M.—A PILOT-PLANT STUDY OF A NEW PROCESS FOR MANUFACTURING AMMONIUM NITRATE, J. J. Dorsey, Jr., Commercial Solvents Corp., Terre Haute, Ind.

2:40 P.M.—THE CHEMICO UREA PROCESS, Lucien H. Cook, Chemical Construction Corp., New York, N. Y.

3:20 P.M.—FACTORS INFLUENCING THE CHANGING TECHNOLOGY OF THE FERTILIZER INDUSTRY, F. A. Retzke, G. F. Sachsel, and R. D. Filbert, Jr., Battelle Memorial Institute, Columbus, Ohio.

For those who like to dance, several of the large hotels have top-notch orchestras playing both at dinner and later. Less formal spots also abound in Washington, as in all large cities.

Other Activities

Sunday morning offers many church services near the Statler Hotel. The President and Mrs. Eisenhower usually attend the 9 or 11 o'clock service at National Presbyterian, 18 and N Streets (just 5 blocks away). St. Matthew's Cathedral (Roman Catholic) is one block closer, on Rhode Island Avenue between 17 and 18 Streets. Episcopalians will find St. John's on 16 at H Street, just two blocks from the Statler. Baptists who would like to attend former President Truman's church will find that it is being rebuilt on its old site (16 and O Streets). During this reconstruction the congregation is meeting at the neighboring Jewish Community Center, just five blocks from the Statler. In the same block, at 16 and P Streets, the Senate Chaplain preaches at Foundry Methodist Church.

Capitol at night, Washington, D. C.

Those seeking a Jewish service on Friday evening or Saturday morning will be welcomed by the Washington-Herbew Congregation at 816 8 Street, the only Reformed service in Washington, or by the numerous orthodox or conservative synagogues throughout the city. Soon there will be Mohammedan services at the mosque in the 2500 block of Massachusetts Avenue, but for now it serves only as a tourist attraction while construction is being completed. On Sunday afternoon sightseeing can be resumed, with a look from the top of Washington Monument, a stroll by the Tidal Basin or Potomac River, or a visit to Lincoln or Jefferson Memorial, to the National Museum or Smithsonian Institution, or to the Archives Building. Other Sunday attractions include the Aquarium (in the Commerce Department building), the Zoo, the Corcoran

and National Galleries of Art, Georgetown, and the Franciscan Monastery.

Monday evening offers an unusual opportunity to lovers of church architecture and choral music who may attend the A.I.Ch.E. meeting. That is the regular rehearsal night for the Washington and Cathedral Choral Societies, preparing for the next (May) concert in the Washington Cathedral. Although the building itself is open to visitors only between 9 and 5, much of its beauty can be seen in the choir and north transept during the rehearsal (8 to 10 p.m.). Enter the north transept door on Woodley Road at 36 Street. Paul Callaway, Cathedral organist, conducts this mixed chorus of 200 voices.

Plant Trips

There are nine plant trips scheduled, two of which are the sightseeing trips already described briefly under the Social Program. Six of the remaining trips are to Federal laboratories for research and development. The other destination is a commercial establishment which has practiced chemical engineering on a large scale for many years, Washington's only brewery.

1. Sightseeing, interior of public buildings, Monday afternoon. See Social Program for details.

2. Naval Ordnance Laboratory, White Oak, Md., Monday afternoon. Wind tunnel, soundproof room, magnetic materials laboratory are among the highlights. Buildings 5 to 10 years old, 10 miles from Statler. Limit: 60, U. S. citizens only.

3. Naval Research Laboratory, Monday afternoon. Crystal growth, cryogenic experiments, Van de Graaf generator will be seen. Buildings 10 to 30 years old, 5 miles from Statler. Limit: 120, U. S. citizens only.

4. Sightseeing, Arlington-Alexandria-Mt. Vernon, Va., Tuesday morning and lunch. See Social Program for details.

5. National Bureau of Standards, Tuesday morning. Chemical process and basic research, and standard materials testing are among the highlights. Buildings 10 to 50 years old, 4 miles from Statler. Limit: 120.

6. David Taylor Model Basin, Carderock, Md., Tuesday morning. Wind tunnels, water tunnels, and water basins for testing scale models will be seen. Buildings 10 to 20 years old, 10 miles from Statler. Limit: 100, U. S. citizens only.

7. Christian Heurich Brewing Co., Tuesday afternoon. Small, interesting brewery. Buildings 50 to 80 years old, 2 miles from Statler. Limit: 40.

8. Naval Powder Factory, Indian Head, Md., Tuesday afternoon. Research, production, and testing facilities will be shown. Buildings 10 to 50 years old, 30 miles from Statler. Limit: 40, U. S. citizens only.

9. Bureau of Mines Experiment Station, College Park, Md., Tuesday afternoon. Mineral-dressing pilot plant, hydrometallurgical research, titanium fabrication and testing laboratory are among the highlights. Limit: 100.

LOCAL SECTION

Addressing the Dallas Chemical Engineer's Club at the January, 1954, meeting, D. M. Updegraff, microbiologist for the Magnolia Petroleum Co., stated that sulfate reducing bacteria have been found responsible for corrosion of external surfaces of well casing at depths of 5,000 ft. below the surface. Though this type of corrosion is recognized for surface conditions, he remarked, new research discloses that soil bacteria are present in an active state at considerable depths.

Officers elected for the year 1954 are:

Chairman............Ovid Baker
Vice-Chairman.....Howard Koch
Treasurer...........Harold Blum

R. A. Graff wants this fact noted— the Club is now entering the second year of operation.

Congratulations to the Chemical Engineering Society of Central Oklahoma! It was authorized as a section at the last meeting of Council. The society wishes to extend thanks to C. N. Ford of the Institute Sections Committee, and the Oklahoma and Tulsa sections for their aid and encouragement in the cause of "our petition." According to the report submitted by Eugene E. Woodward, secretary-treasurer of the society, the year 1953, the second full year of the organization's existence, was a successful one. The society, which boasted of twenty-eight members in good standing, met eight times during that year. Six of the meetings were technical, one a plant trip, and one a social meeting with the distaff side as welcome guests.

The following officers for 1954 were announced at the annual meeting.

Chairman—John Campbell, Black, Sivalls and Bryson

Vice-Chairman—E. E. Woodward, Kerr-McGee Oil Industries, Inc.

Secretary—R. A. Morgen, Black, Sivalls & Bryson

Executive Committeemen—C. H. Kopp, Peppers Refining Co., Bill Hastings, Black, Sivalls & Bryson and

Ex officio—K. E. Hutchison, Kerr-McGee Oil Industries, Inc.

Jan. 6, 1954, was Student Chapter Night when the Detroit Section was visited by engineering students from schools in the locality. These potential engineers witnessed a film presentation of "Cement Manufacture and Uses."

The Rochester Section held its Jan. 20 meeting at the Rundel Memorial Library. The meeting was preceded by a dinner at Lorenzo's Restaurant. H. J. Bowen, president of Industrial Models, Inc., spoke on the use of industrial models and the economics of this type of engineering design and planning which, William H. Eilinger, Rochester reporter, says has been questionable to many of us.

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman, A.I.Ch.E. Program Committee
   Loren P. Scoville, Jefferson Chemical Company, Inc.   260 Madison Ave., New York 16, N. Y.

Assistant Chairman
   George Armistead, Jr., George Armistead & Co.   1200 18th St., N.W., Washington, D. C.

MEETINGS

Washington, D. C., Statler Hotel, March 7-10, 1954.

Springfield, Mass., Hotel Kimball, May 16-19, 1954.

Ann Arbor, Mich., Univ. of Mich., Ann Arbor, Mich., June 20-25, 1954—Conference on Nuclear Engineering.
TECHNICAL PROGRAM CHAIRMAN: D. L. Katz, Chairman, Dept. of Chem. and Met. Eng., Univ. of Mich., 2028 E. Eng. Bldg., Ann Arbor, Mich.

Glenwood Springs, Colo., Hotel Colorado, Sept. 12-15, 1954.
TECHNICAL PROGRAM CHAIRMAN: Dr. Charles H. Prien, Head, Chem. Div., Denver Res. Inst., Univ. of Denver, Denver 10, Colo.

Annual—New York, N. Y., Statler Hotel, Dec. 12-15, 1954.
TECHNICAL PROGRAM CHAIRMAN: G. T. Skaperdas, Assoc. Dir., Chem. Eng. Dept., M. W. Kellogg Co., 225 Broadway, N. Y. 7, N. Y.
ASST. CHAIRMAN: N. Morash, Titanium Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

Louisville, Ky., Kentucky Hotel, March 20-23, 1955.
TECHNICAL PROGRAM CHAIRMAN: R. M. Reed, Tech. Dir., Gas Proc. Div., The Girdler Corp., Louisville 1, Ky.

Houston, Texas, Shamrock Hotel, May 1-4, 1955.
TECHNICAL PROGRAM CHAIRMAN: J. L. Franklin, Res. Assoc., Humble Oil & Refining Co., P. O. Box 1111, Baytown, Texas.

Lake Placid, N. Y., Lake Placid Club, Sept. 25-28, 1955.
TECHNICAL PROGRAM CHAIRMAN: L. J. Coulthurst, Chief Proc. Designer, Foster Wheeler Corp., 165 Broadway, New York 6, N. Y.

Annual—Detroit, Mich.—Statler Hotel, Nov. 27-30, 1955.
TECHNICAL PROGRAM CHAIRMAN: T. J. Carron, Head, Chemical Tech. Office, Ethyl Corp., Res. Labs., 1600 West Eight Mile Road, Detroit 20, Mich.

Los Angeles, Calif., March, 1956.
TECHNICAL PROGRAM CHAIRMAN: T. Weaver, Proc. Eng., The Fluor Corp., Ltd., Box 7030, East L. A. Station, Los Angeles 22, Calif.

SYMPOSIA

SYMPOSIA FOR SPRINGFIELD MEETING

Polymeric Materials of Construction

Process Design

Nuclear Engineering

CHAIRMAN: D. L. Katz, Chairman (Address: See Ann Arbor Meeting).

MEETING—Ann Arbor, Mich.

Agglomeration

CHAIRMAN: A. P. Weber, International Engineering, Inc., 15 Park Row, New York, N. Y.

MEETING—Glenwood Springs, Colo.

Uranium Processing and Refining

CHAIRMAN: R. H. Long, Vitro Eng. Div., Vitro Corp., 120 Wall St., New York, N. Y.

MEETING—Glenwood Springs, Colo.

Reaction Kinetics

CHAIRMAN: N. R. Amundson, Dept. of Chem. Eng., Univ. of Minnesota, Minneapolis 14, Minn.

MEETING—New York, N. Y.

Gas Absorption

CHAIRMAN: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

MEETING—New York, N. Y.

Solvent Extraction

CHAIRMAN: Dr. R. B. Beckmann, Dept. Chem. Eng., Carnegie Inst. of Tech., Schenley Park, Pittsburgh 13, Pa.

MEETING—New York, N. Y.

Fluidized Solids

CHAIRMAN: N. Morash, Tit. Div., National Lead Co., P. O. Box 58, South Amboy, N. J.

MEETING—New York, New York

Heat Transfer

CHAIRMAN: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

MEETING—Louisville, Ky.

Nucleation Processes

CHAIRMAN: D. W. Oakley, Plant Mgr., Metal & Thermit Corp., 1 Union St., Carteret, N. J.

MEETING—Houston, Tex.

Centrifugation

CHAIRMAN: J. O. Maloney, Chairman, Dept. Chem. Eng., Univ. of Kansas, Lawrence, Kan.

Submitting Papers

Members and nonmembers of the A.I.Ch.E. who wish to present papers at scheduled meetings of the Institute should follow the following procedure.

First, write to the Secretary of the A.I.Ch.E., Mr. S. L. Tyler, American Institute of Chemical Engineers, 120 East 41st Street, New York, requesting three copies of the form "Proposal to Present a Paper Before the American Institute of Chemical Engineers." Complete these forms and send one copy to the Technical Program Chairman of the meeting for which the paper is intended, one copy to the Chairman of the A.I. Ch.E., Program Committee, address at the top of this page, and one copy to the Editor of Chemical Engineering Progress, Mr. F. J. Van Antwerpen, 120 East 41st Street, New York.

If you wish to present the paper at a particular symposium, one copy of the form should go to the Chairman of the symposium instead of the Technical Program Chairman of the meeting.

Before Writing the Paper

Before beginning to write your paper you should obtain from the meeting Chairman, or from the office of the Secretary of the A.I.Ch.E., at 120 East 41st St., New York, a copy of the A.I.Ch.E. Guide to Authors, and Guide to Speakers. These cover the essentials required for submission of papers to the A.I. Ch.E. or its magazines.

Copies of Manuscript

Five copies of each manuscript must be prepared. For meetings, one should be sent to the Chairman of the symposium, and one to the Technical Program Chairman of the meeting at which the symposium is scheduled. If no symposium is involved, the two copies should be sent to the Technical Program Chairman. The other copies should be sent to the Editor's office since manuscripts are automatically considered for publication in Chemical Engineering Progress, or the symposium series of Chemical Engineering Progress, but presentation at a meeting is no guarantee that they will be accepted.

DEADLINE DATES FOR PAPERS

ANN ARBOR MEETING—February 15, 1954

GLENWOOD SPRINGS MEETING—May 12, 1954

NEW YORK MEETING—August 12, 1954

LOUISVILLE MEETING—November 20, 1954

HOUSTON MEETING—January 1, 1955

LAKE PLACID MEETING—May 25, 1955

DETROIT MEETING—July 27, 1955

LOCAL SECTION NEWS
(Continued from page 71A)

Carl M. Kron, reporting on the Texas Panhandle Section, sends in the names of the officers for 1954. They are as follows:

Chairman...............Howard Weaver
Vice-Chairman...............E. H. Gray
Secretary...................T. S. Whitsel
Treasurer....................W. B. Polk
Directors......S. A. Blundell, C. M. Kron, and L. A. Webber

Kron's report states that a session was held in December for the purpose of informing students in the area of some of the duties of engineers in industry. The attendance at this meeting was 59, of which 18 were college students and 2 were high school students.

At their most recent meeting the members of the newly organized New Haven Chemical Engineers' Club elected the following officers for 1954:

Chairman—Walter S. Kaghan, Olin Industries, Inc.
Vice-Chairman—E. Leonard Borg, Naugatuck Chemical Co.
Secretary—Joseph J. Levitzky, Olin Industries, Inc.
Treasurer — Shepherd Lippa, Sponge Rubber Products Co.
Executive Committeemen—Alan T. Lincoln, American Cyanamid Co.; Raymond W. Southworth, Yale University; Walter C. Wardner, Connecticut Coke Co.; Stanley E. Wilson, Carwin Co.

The January meeting held on Jan. 19 at Yale University featured John F. Bohmfalk, Jr., of Clark, Dodge & Co., whose talk was titled "Stock Market and the Chemical Industry."

Joseph J. Levitsky, reporter, states that speakers David E. Pierce and Roland Ward will address the club in February and March.

J. H. Wardwell has forwarded us the names of the officers of the Midland Section for 1954. They are as follows:

Chairman—K. E. Coulter
Vice-Chairman—J. H. Wardwell, Strosacker's Lab., The Dow Chemical Co., Midland, Michigan.
Secretary-Treasurer—C. D. DeBord, The Dow Chemical Co., Midland.
Members of the Executive Committee—D. F. Burdick, Michigan Chemical Corp., St. Louis; J. Eichhorn, Physical Research Lab., The Dow Chemical Co., Midland.

Ralph H. Munch, group leader in Monsanto's research department, in physical chemistry and instrumentation, spoke on "Instrumentation: Past, Present and Future" to sixty-eight members and guests of the St. Louis Section, at its dinner meeting on Jan. 19, 1954, at the York Hotel. Dr. Munch said that

instrumentation has been a prerequisite to our present scientific knowledge and a factor in this country's productivity. He pointed out that instrumentation was also vital to our national defense, particularly in such fields as guided missiles, atomic energy and jet aircraft.

R. C. Johnson of Washington University, chairman of the section's Education Committee, announced that a subcommittee would furnish speakers to talk to high school students about typical chemical engineering work, and called for volunteers. This would aid the Vocational Guidance committee of the Engineers Club here in its plans to reach students in the eastern half of Missouri and southern Illinois.

Richard Kerlin sent in a full account.

R. R. White of the University of Michigan and currently one of the Humble lecturers at the Baytown refinery, talked before the South Texas Section on Jan. 22, on "New Concepts in Rate Processes." His address followed an inspection trip through the Diamond Alkali Co. Houston Works.

Officers of the Section announced at the December, 1953, meeting are as follows:

Chairman—John J. McKetta, Jr., Petroleum Refiner

Chairman-elect—Guy T. McBride, Jr., The Rice Institute

Secretary—C. L. Fitzgerald, Jr., Maintenance Engineering Corp.

Treasurer—W. R. Trutna, Du Pont Co.

Executive Committee—Neil McKay, Jr., Shell Chemical Co.; C. E. Lyon, Diamond Alkali Co.; E. J. Fox, Carbide & Carbon; W. B. Franklin, Humble Oil & Refining Co., ex officio.

The Central Ohio Section joined the local sections of the A.S.M.E. as guests of the local section of A.C.S. on Jan. 11, 1954, to hear an address by Clifford F. Rassweiler, vice-president of research and development of the Johns-Manville Corp. Dr. Rassweiler discussed "The Role of the Chemist or Engineer in Business Management," in the McPherson Laboratory on the campus of The Ohio State University. Preceding the address, the chemical engineers gathered for a dinner at The Ohio State University Faculty Club.

George F. Sachsel again reported.

Harold L. Nicholson reports that the annual ladies night meeting of the Akron Section was held at the Akron Art Institute, Jan. 14, and was attended by approximately 100 members, ladies and guests.

George D. Culler, director of the Art Institute, served as moderator for a panel discussion on the subject—"What Design Today Can Do for Your Home."

Two gallery exhibits at the Institute were viewed: "The Creative Needlework" by Mariska Karasz, and "The Camera as a Third Eye," a photographic record of the old houses of Louisiana, by Clarence John Laughlin.

New officers of the Maryland Section elected for the calendar year 1954 are as follows:

Chairman..Elmer L. Knoedler, Jr.
Vice-Chairman......L. C. Palmer
Secretary......Thomas O. Tongue
Treasurer.........Leslie Herbert
Executive Committee: L. J. Trostel, John J. Brown, and James G. Hough

The Sabine Area of the A.I.Ch.E. will hold its first joint meeting with the Texas-Louisiana Gulf Section of the A.C.S. on March 26, 1954.

For this all-day session a program has been prepared to cover a broad range of topics including water resources of this area, tax and other problems regarding the movement of natural gas from Texas, and tariff laws under consideration in Congress which affect the chemical industries.

The New Orleans Section held a dinner meeting on Dec. 1, 1953, at the Engineers and Architects Club of New Orleans. The speaker of the evening was Robert W. Elsasser, business counselor in the New Orleans area, whose subject was "Current Economic Symptoms." The speech was preceded by a business meeting.

Officers of the local section for the year 1954 are as follows:

Chairman......Francis M. Taylor
Vice-Ch'm'n..Walter Godchaux, Jr.
Secretary............Hugh Black
Treasurer............Carl Peters
Executive Committeemen:
Henri J. Molaison
Raymond V. Bailey
J. W. Bertetti

Alton S. Hall sent in this information.

Officers of the Baton Rouge Section for 1954 are as follows:

Chairman................L. H. Stephens
Vice-Chairman............B. S. Pressburg
Secretary................T. C. Landrum
Treasurer................H. H. Wall, Jr.
Executive Committee....E. P. Breidenbach, G. E .Montes, L. A. Nicolai, and R. W. Krebs

James M. Gill, secretary (1953), sent in a résumé of the year's activities. He referred to the ninth and annual dinner meeting of the year 1953 which was held at the Heidelberg Hotel with forty-five members and guests in attendance. The guest speaker was K. M. Watson, director of research, The Pure Oil Co.

Dr. Watson's talk was titled "Objectives in Chemical Engineering Education." Criticizing present methods of college education, Dr. Watson said, "A substantial percentage of graduates who eagerly clutch their sheepskins should never have left the farm." He explained that under his plan, exceptional students would enter college after only two years of high school. They would enter a pre-engineering course of two years, followed by a regular four-year course; completion would merit the student a professional degree of chemical engineering.

The Northeastern New York Section held a joint meeting with the American Society for Quality Control, Jan. 12 in Menands. The speaker for the evening was Frank Wilcoxon of the American Cyanamid Co., whose subject was "Rapid Approximation of Statistical Procedure." Dr. Wilcoxon described certain graphical and mathematical methods, which permit rapid approximations of lengthy statistical formulae. A. C. Schafer says the technical session was preceded by a dinner.

The Knoxville-Oak Ridge Section, through H. C. McCurdy, reporter, has announced the officers for the year 1954. They are as follows:

Chairman.................John Shacter
Chairman-elect............H. F. Johnson
Secretary.................R. P. Milford
Treasurer.................P. A. Haas
Directors........W. B. Allred, R. N. Lyon
H. C. McCurdy

"Light Sorcery," a dramatic presentation of the development of the incandescent bulb from its inception to its present state of development, was shown before the Jan. 21 meeting of the Rhode Island Section by R. H. Wilson, sales promotion manager, lamp division, General Electric Co.

Morton Port, Rhode Island Section Secretary, in his report said that the program chairman had started a preliminary investigation into the possibility of the section's affiliation with the Providence Engineering Society, and that he would arrange for a speaker on atomic energy for a future meeting.

—H.R.G.

IOWA IS ACCREDITED

Karl Kammermeyer, professor of chemical engineering at the State University of Iowa, has called our attention to a change in the accrediting status of the university. The Chemical Engineering Faculty Bulletin, prepared by the Chemical Engineering Education Projects Committee of the Institute, was issued before the recent action of the Engineers' Council for Professional Development in concurring with the Institute's accrediting of the State University of Iowa. The statement there that the State University of Iowa is not accredited by the A.I.Ch.E. is therefore incorrect at this time.

Copies of the faculty list are available free, upon request to the Secretary of the Institute.
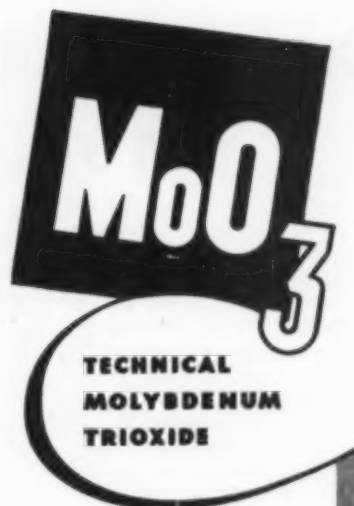
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   (125 pages; $3.75 to members, $4.75 to nonmembers)

5. **Heat Transfer—Atlantic City**
   (162 pages; $3.25 to members, $4.25 to nonmembers)

6. **Phase-Equilibria—Collected Research Papers for 1953**
   (113 pp.; $3.25 to members, $4.25 to nonmembers)

7. **Applied Thermodynamics**
   (163 pages; $3.25 to members, $4.25 to nonmembers)

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PEOPLE

Richard J. Kozacka, operating superintendent of the alkyl benzene and phosphoric acid departments, William G. Krummrich plant, Monsanto Chemical Co., since 1952, is now general manufacturing superintendent for the inorganic chemicals division products being manufactured in plants which are a part of the company's organic chemicals division. His responsibilities will be principally at the William Krummrich plant at Monsanto, Ill., but will also include plants at Nitro, W. Va., and Avon, Calif. Mr. Kozacka obtained his B.S. degree in chemical engineering from the University of Michigan in 1940 and joined Monsanto in the same year.

David S. Bruce, was recently appointed director of operations of the cellulose products department, Hercules Powder Co., Wilmington, Del. He first joined the company at its explosives department plant at Hercules, Calif., in 1936. During World War II, he was employed in ordnance plants operated by the company and was active in the development of rocket powder. He was transferred to the Parlin, N. J., plant of the cellulose products department in 1946 as acetate supervisor, later becoming acetate superintendent and then assistant plant manager, and in January, 1952, he was made manager of new product promotion.

Thomas K. Sherwood, professor of chemical engineering at Massachusetts Institute of Technology, has been retained by The Fluor Corp., Ltd., of Los Angeles, as a consultant to its research and development division. He will consult on Fluor's long-range research planning and advise in the prosecution of current projects. Dr. Sherwood is a director of Arthur D. Little, Inc., and is also a consultant for other companies in the petroleum and chemical fields. During World War II, Dr. Sherwood actively participated in several armed forces research and development programs, for which he received the U. S. Medal for Merit.

H. K. Waters   **G. Kleinman**

Swenson Evaporator Co. recently announced the assignment of **Harvey K. Waters** to the Birmingham district office, Birmingham Ala., and of **George Kleinman** to the Houston, Tex., district office. After completing Whiting's extensive sales training program, these men were assigned to the field force to serve better the growing needs of the process industries. Mr. Waters received his B.S. and M.S. degrees from Michigan College of Mining and Technology. He has been at the Harvey, Ill., plant of Swenson for the past four years. Mr. Kleinman, a graduate of Illinois Institute of Technology, has been in training with the company for four years.

Robert J. Wolf is now director of development at the Avon Lake, Ohio, experimental station and **Benjamin M. G. Zwicker** is coordinator of product development in the Cleveland headquarters, both for B. F. Goodrich Chemical Co.

Dr. Wolf received his Ph.D. in chemical engineering from Case Institute of Technology in 1942, and taught at Princeton University prior to serving three and one-half years with the Navy. He joined B. F. Goodrich in 1946, holding various positions in Geon polyvinyl chloride resin development until his appointment as manager, sales development laboratory in 1952.

Dr. Zwicker began with BFG in 1940 as a research chemist, becoming technical manager, development, of the Akron experimental station in 1943, and then manager of that station in 1948. Since 1950 he has been serving as technical analyst for development programs of BFG Chemical Co. Graduated from Whitman college with a B.S. degree in physics, chemistry and mathematics in 1935, he then attended the University of Washington, receiving his M.S. degree in chemistry, and in 1940 was graduated with a Ph.D. in chemistry.

Arnold Arch has been appointed director of air pollution control for the city of Niagara Falls, N. Y. Prior to this appointment he had been serving as contracting officer's representative at the Niagara Falls Chemical Corp. plant while a major on active duty with the U. S. Army Chemical Corps.

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BARKER FAMILY OPENS PLASTICS FIRM

Family album: left to right, E. R. Barker, K. T. Barker, and E. R. Barker, Jr.

A chemical engineering family whose combined experience spans almost the entire modern chemical engineering age, has joined forces in one of the newer chemical fields. Elliott R. Barker, who received a bachelor's degree in chemistry and engineering from Massachusetts Institute of Technology in 1898, and his sons Kenneth and Elliott, Jr., chemical engineering graduates of the universities of New Hampshire and Maine respectively, have established a plastics extrusion firm in South Deerfield, Mass. Known as the Deerfield Plastics Co., Inc., the firm specializes in high-precision cellulose acetate and butyrate tubing and in the production of containers from such tubing.

Kenneth T. Barker, general manager, was senior chemical engineer and operating superintendent of the plastics division of Monsanto Chemical Co. from 1945 to 1949 and afterwards chief engineer at DeBell & Richardson, Inc., and Shore Line Industries, Inc. Elliot R. Barker, Jr., production manager, was with the Hollingsworth-Whitney Paper Co. from 1931 to 1953 in various engineering capacities. Elliott, Sr., was a chemical engineering consultant and equipment designer from 1906 to 1941 and has emerged from semiretirement to become president of the new firm.

The new manager of research, development and engineering, Shell Chemical Corp., is A. W. Fleer, formerly manufacturing operations manager. Dr. Fleer received his Ph.D. in chemical engineering from the University of Michigan and started his career with Shell as a technologist at St. Louis in 1935, and in 1944 became technical assistant to the president of Shell at San Francisco.

Elliott J. Roberts has been named a vice-president of The Dorr Co., Stamford, Conn. Dr. Roberts, formerly the company's technical director in charge of research, development and the Westport Mill, received his B.S. degree in chemistry, (1925), and his Ph.D. (1928) from Yale University. From 1928 to 1930 he remained at Yale as an instructor in physical chemistry and qualitative analysis, and at the same time he served as a consultant to the Dorr Co. on chemical investigations. He joined the company full time in 1930 with headquarters at the Westport, Conn., laboratories, initially as a research chemist, later becoming director of research.

Martin de Simo, formerly assistant sales manager, was recently elected a vice - president, Chemical Construction Corp. At the same time Thomas P. Forbath was named assistant to the president. Prior to joining the company, de Simo was technical director of sales for Foster Wheeler Corp., an independent consultant in Chicago, vice-president in charge of research at the Great Lakes Carbon Corp., and head of the organic chemicals and petroleum processing department, Shell Development Co. Mr. Forbath was formerly chief of the research and development division for Chemical Construction. He received his B.S. and Ch.E. degrees from Columbia University.

M. de Simo

Frederic W. Hammesfahr is now manager of the chemical process development section of the chemical division's engineering department at General Electric. He was formerly a supervisor in chemical process development. Prior to his association with GE, he was with the General Tire & Rubber Co. as a development engineer.

Myrl E. Miller is now manager of process development for the engineering planning department of the chemical research and engineering division, Mathieson Chemical Corp., Baltimore, Md. He was formerly assistant operations manager of the company's Pasadena, Tex., plant and previous to this was engaged in a special Mathieson research project at Ohio State University. Before joining the corporation, he was an assistant in the university's department of chemical engineering. Dr. Miller received his B.S., M.S., and Ph.D. degrees in chemical engineering from Ohio State University.

DAVID E. PIERCE

Chemical engineer, author and lecturer, and appointee to the newly created position of director of manufacturing control at Diamond Alkali Co. Formerly chief of the General Aniline & Film Corp., New York, for ten years, Mr. Pierce previously had been associated in a similar capacity from 1927 to 1942 with Rohm & Haas Co., Philadelphia. He has also been identified with the Atlantic Refining Co., Philadelphia, and with Du Pont Co. In joining Diamond's national headquarters in Cleveland, Pierce leaves New York, where he has operated his own consulting engineering business at 52 Wall Street for the past year.

The appointment of **William R. Ludka** as director of staff laboratories engineering was recently announced by Minnesota Mining & Manufacturing Co. Ludka will be responsible for all engineering connected with 3M's central research and products fabrication departments as well as for its new products and defense products departments. He will also continue as head of the firm's chemical engineering staff. He received his M.S. degree from the University of Wisconsin in 1942.

J. S. Gilliam, formerly chief process engineer, is now superintendent of the organic department of the hydrocarbon chemicals division, Mathieson Chemical Corp., Morgantown, W. Va.

E. F. WAGNER

E. F. Wagner has been appointed manager of Witco Chemical Company's Chicago plant. He will continue serving also as director of the technical service department. Prior to joining Witco in 1945, he served as chemical engineer with Standard Oil Company of Ohio. Dr. Wagner received his doctorate from Illinois Institute of Technology.

CLASSIFIED SECTION

SITUATIONS OPEN

Address Replies to Box Number Care of CHEMICAL ENGINEERING PROGRESS

CHEMICAL ENGINEER

Interesting opportunity for work in process evaluation, design, and pilot plant work in the petroleum chemical field for a capable, experienced engineer on program being carried on in conjunction with Electric Bond and Share Co. and United Gas Corporation.

National Research Corporation

70 Memorial Drive

Cambridge, Massachusetts

CHEMICAL ENGINEERS

June 1954 graduates or men with few years experience for production administration and supervision in established international organization, manufacturing toilet articles, soaps and detergents.

Preferably under 28, willing to travel, with possibility foreign assignment. This is an excellent opportunity and a career position offering unusual possibilities for advancement.

Please submit complete details, education and experience.

Personnel Department
COLGATE-PALMOLIVE CO.
105 Hudson St.   Jersey City, N. J.

COMBUSTION ENGINEER — Wanted by a glass company in the Midwest. Must have a technical background and familiarity with the burning of fuels in industrial processes, especially natural gas, oil and other fuels including coal. Box 5-2.

CHEMICAL ENGINEERS — Permanent positions open in production supervision and area engineering with a medium-sized corporation located in Massachusetts. Please write details of education, experience and salary requirements. Privacy is assured. Box 6-2.

PROCESS ENGINEER — Young man, under 35, with degree in chemical engineering or petroleum engineering (refinery). Up to three years' experience in oil refinery process work desirable but not absolutely necessary. Permanent position with a Texas Gulf Coast refinery. Please give complete personal résumé. Box 7-2.

CHEMISTS
MS or PhD PREFERRED

CHEMIST OR CHEMICAL ENGINEER (R-91)

Experienced in high pressure hydrogenation and alkylation reactions.

ORGANIC-INORGANIC CHEMISTS (R-98)

Experienced in high vacuum technique, inorganic synthesis or organo-metallic research.

LET'S TALK FACTS ABOUT ROCKET POWER

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A comparatively small company, RMI provides an ideal, stimulating environment for young chemists with imaginative, inquisitive minds. Located in the Lakeland region of New Jersey, renowned vacation playground, RMI offers ideal year-round living conditions with ample housing.

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Write: Employment Manager

Please indicate job number in your application

REACTION MOTORS, INC.
Leading Designers and Developers of Rocket Power
ROCKAWAY, NEW JERSEY
LESS THAN 1 HOUR FROM TIMES SQUARE

CHEMICAL ENGINEER — For process development and design work in small metropolitan New Jersey plant. Must have experience in production and process development in organic chemicals and a good scholastic background. Starting salary approximately $7,000. Box 8-2.

SALES REPRESENTATIVES WANTED — To handle proportioning chemical feed pumps. Precise, reinforced-diaphragm type pumps of non-corrodible materials. Used for accurate pumping of water conditioning chemicals, also metering of various solutions in process industries. Substantial discount, protected territory arrangement possible. Box 9-2.

SALES TERRITORIES AVAILABLE

Large manufacturer quality corrosion resisting coatings and linings seeking additional sales representatives or companies with related lines. Protected territories available. Ability to follow furnished leads, close sales, imagination to develop new markets essential. Repeat business on established accounts. Extensive research facilities and strong office support. Indicate territory and lines now covered. Carboline Co., 331 Thornton, St. Louis 19, Mo.

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER—PRODUCTION MANAGEMENT—Age 36. M.Ch.E. Twelve years' experience includes resident manager of alcohol plant; chief engineer of eight plant organization; assistant to vice president in charge of production. Seeking responsible position in production, management or plant engineering. Box 1-2.

PROJECT ENGINEER—P.E. Presently consultant in plant layout and equipment design. Available on consultant arrangement to firm requiring engineer for project management or assistance in obtaining new work. New York area preferred. Box 2-2.

TECHNICAL EXECUTIVE—Age 43. Have demonstrated top qualifications in research and development, all aspects of chemical plant design, and production operations. Know processes, kinetics, patents and organization control. Box 3-2.

CHEMICAL ENGINEER — B.S.Ch.E. 1953. Married, age 25. Desire "part-time" chemical engineering work at home in application, process development or design. Experience in development, research and quality control. N. Y.-N. J. area. Box 10-2.

CHEMICAL ENGINEER — B.S.Ch.E. 1940. Production management. Age 35. Thirteen years large chemical company. Desire responsible position in an aggressive medium-sized company to aid in growth. Present salary $8,700. Box 11-2.

CHEMICAL ENGINEER—B.S.Ch.E. Age 33, family. Twelve years' experience atomic energy fields, process development. Desire development or production position. West Coast preferred. Box 12-2.

CHEMICAL ENGINEER — M.S.Ch.E. 1948. Veteran. Plant and equipment design, economic evaluations. Supervisory experience in maintenance and construction. Purchasing and contract negotiations. Responsible for projects valued in excess of $100,000 per year. Proven initiative and imagination. Box 13-2.

CHEMICAL ENGINEER—Age 33, Ph.D. Seven years' varied organic and inorganic experience. Desire permanent staff position in engineering or process development with small or medium-sized company. Box 14-2.

CHEMICAL ENGINEER — B.S. 1950. 3½ years' experience as plant engineer in Portland cement manufacturing mill, including investigation of improvements of manufacturing processes, quarry development, and layout design and estimation of new equipment. Veteran, age 27, married, family. Box 15-2.

ADMINISTRATIVE POSITION directly responsible to top management for research and technical developments desired by licensed chemical engineer. Ph.D., employed. "Idea man" of proven ability in chemical and petroleum industries. Fifty patents; publications. Box 16-2, Chemical Engineering Progress.

PETROLEUM AND CHEMICAL ENGINEERING SERVICES — Process calculations, operating manuals, economic evaluations performed accurately and promptly. Relieve your technical men for other urgent work. Try this courteous service. Box 17-2.

CHEMICAL ENGINEER—B.S. Age 29, married, U. S. citizen. Desire challenging position of responsibility in or leading to Mexico or S. A. Five years' diversified experience in petrochemical industry including process design and production supervision. Box 18-2.

CHEMICAL ENGINEER—A.B., Ch.E. Thirty years' experience including direction large process development group, start-up plant operation new processes, on the spot investigations German technology, technical advisory activities. Desire position executive or assistant executive. Box 19-2.

CHEMICAL ENGINEER—26. B.Ch.E. Cooper Union. 2½ years' experience process design, equipment design, research and development. Desire to relocate in San Francisco or Los Angeles area. Box 20-2.

CHEMICAL ENGINEER — MANAGEMENT — Cornell 1943, Alexander Hamilton Institute. One employer affiliation since graduation; assistant to president, manager research and development department, sales engineer, petroleum refinery engineer, pilot-plant supervisor in reverse order. Credit manager and chemical operator prior to graduation. Present salary $12,400. Age 34, married, three children. Seek connection with chemical or petrochemical manufacturer. Line or staff work in manufacturing, operations planning or economics. Box 21-2.

CONSULTING CHEMICAL ENGINEER — Formerly with leading Canadian chemical company. Large experience in the manufacture of heavy chemicals, plant design and process development. Available to work in Canada for engineering and construction companies. Box 22-2.

CHEMICAL ENGINEER — B.Ch.E. 1949, veteran. Four years' experience in plant engineering, pilot plant and process development with large company. Desire to relocate for more general experience. Available immediately. Box 23-2.

PLANT SUPERINTENDENT — B.S.Ch.E. Family, age 31. Ten years of production management including operating, maintenance, engineering, safety, personnel, and labor relations. Fully responsible for the operation and maintenance of boilers, engines, chemical processes, refrigeration equipment, purchasing, and authorization of contractors. Capable of successfully handling increased responsibilities. Northeastern area. Available March. Box 24-2.

SENIOR PROCESS ENGINEER—B.Ch.E. Age 34. Considerable pharmaceutical and other chemical experience. More than eleven years diversified practice in production, development, installation, break-in, purchasing, process and project design. Nine years pharmaceutical; two years chief engineer and process design consultant. Desire supervisory position in process design. N. Y. metropolitan area preferred. Box 25-2.

CHEMICAL ENGINEER — Ph.D. Business training and ten years' research, development and engineering experience in organic, heavy and petrochemicals. Desire opportunity to develop interests in chemical economics and commercial development in addition to technical activities. Box 26-2.

Nonmembers

COATING LAMINATING, EXTRUSION, IMPREGNATION, gravure printing, foil rolling, vacuum metal evaporation and refining. Rubber, plastics, thermosets and latex. Aluminum, papers, films, textiles. Classified defense and commercial. Extreme temperature conditions. At present chemical director, AaA-1 multiplant company which operates in all these fields. Wish to change; available for two days per week on permanent basis. Development, production or marketing. Individual problem, or general supervision or special conditions. Box 4-2.

WILL YOU SELL MORE IN '54? Let a fast talking chemical engineer help you. Write Box 27-2.

PEOPLE

Herman R. Thies has been promoted to general manager of all chemical products for the Goodyear Tire & Rubber Co., Akron, Ohio, to coordinate the supplying of chemical raw materials. Thies joined Goodyear in 1930 as a rubber research compounder and, in 1936, was made assistant director of research, advancing to manager of Pliolite sales in 1942. He became head of the plastics and coating department in 1945 and was made manager of Goodyear's chemical division when it was first organized in 1948. Among Thies's major accomplishments in the chemical field is his development of Pliolite NR, a cyclized product from natural rubber.

R. D. Hemminghaus   F. J. Soday

The recent appointments of **Roy G. Hemminghaus** and **Frank J. Soday** as vice-presidents of The Chemstrand Corp., a jointly owned associate company of American Viscose Corp. and Monsanto Chemical Co., with corporation headquarters located at Decatur, Ala., was recently announced.

Mr. Hemminghaus is plant manager of Chemstrand's nylon-filament-yarn-manufacturing facilities now under construction near Pensacola, Fla. Prior to joining Chemstrand, in 1950, he had completed twenty years of service with Monsanto Chemical Co. As vice-president, he will continue to be in charge of nylon plant operations.

Dr. Soday, who holds approximately 130 U. S. patents, is director of research and development for Chemstrand and will be vice-president and director of these same activities at the firm's research center. He previously was associated with Lion Oil Co., Devoe & Raynolds Co., Inc., Copolymer Corp., United Gas Improvement Co., and Monsanto Chemical Co.

DIRECTIONS FOR USE OF CLASSIFIED SECTION

A. O. Zoss was recently named technical director of the Linden plant of General Aniline & Film Corp. Formerly production manager, Dr. Zoss in his new post is responsible for production, engineering, process development, and process engineering functions. He joined the company at Grasselli in 1941 as a research chemist and, in 1943, was transferred to the company's central research laboratory, Easton, Pa., where he specialized in high pressure acetylene research. He returned to the Linden plant in 1947 as a chemist in the special products department and was named superintendent two years later.

C. E. Lyon, vice-president and works manager of Diamond Alkali Co.'s Houston plant since it was put into production in 1948, has recently been named general manager of the new chlorinated products division. Succeeding Lyon as works manager of the Houston plant, is **Frank Chrencik,** who has been assistant works manager there for the past six years, and was previously superintendent of Diamond's Edgewood, Md. electrochemical plant.

The appointment of **Robert C. Anderson** as assistant director of engineering for staff laboratories was announced recently by Minnesota Mining & Manufacturing Co. He joined Minnesota Mining as an engineer in 1947 and was assigned to the fluorochemical section of the central research department. Since 1949 he has served as product engineer in the chemical engineering and staff laboratory engineering groups.

Necrology

B. F. RUTH

Burrell Franklin Ruth, professor of chemical engineering in the department of chemical and mining engineering at Iowa State College, Ames, Iowa, died suddenly Jan. 1, 1954.

Born in Traverse City, Michigan, in 1901, Dr. Ruth received his B.S. and M.S. degrees from Michigan State College and his Ph.D. degree from the University of Minnesota. He was a member of the staffs of the University of Minnesota, Texas A & M College and had been in the department of chemical, and mining engineering at Iowa State since 1938. He was also associated with the Institute for Atomic Research at Iowa State College. Dr. Ruth's field of research was in the unit operations of chemical engineering, particularly that of filtration.

A memorial fund has been established for the purpose of providing a book collection for the library of the department of chemical and mining engineering at Iowa State.

INDEX OF ADVERTISERS

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A.I.Ch.E. NEWS AND NOTES

<u>Council</u> last month unanimously passed a motion which is embarrassingly reported here since it concerns us. But far more it concerns the Institute, and its affairs, and it is with verecundity that we pass on to the membership the gist of an action in which we play a part.

First, a new post was created, and we were nominated to fill it -- that of publisher of the A.I.Ch.E.

<u>Second</u>, planning toward the impending retirement of the executive secretary, S. L. Tyler, Council also advised of its plan to make us executive head of institute functions.

<u>Tyler</u> became the first full-time executive secretary of the A.I.Ch.E. in April, 1937, when the Institute had the staggering total of 1,486 members. Since then the progress of the organization has been steadily forward, and it is with a great deal of sadness that we contemplate his leaving the post. The inexorable march of years does not touch him with number sixty-five until late this year, and we shall have several opportunities in later columns to recount his accomplishments, for which we have a sincere respect; for the man we have a warm feeling of kinship.

<u>We</u> have no illusions about the task facing us, and we pledge to do our utmost for the well-being of the chemical engineering profession.

<u>Study of Institute future</u> is continuing. Last month Professor J. H. Rushton accepted the chairmanship of the committee and will organize a group in Chicago to carry on from where last year's report ended.

<u>New student chapter</u> was approved for Lamar State College of Technology, which is located at Beaumont down Texas way.

<u>Constitutional amendments</u> affecting membership nomenclature and nominating procedures were again discussed. More on this on page 56A of this issue. Members had their first go at this at St. Louis; the Washington meeting in March will also feature a business session on the amendments.

<u>Third proposal</u> on the constitutional revamp gives Council permission to form Divisions, under same regulation now providing for Local Sections and Student Chapters.

<u>Membership</u> in the A.I.Ch.E. continues upward. The past several years have seen in operation for the first time a membership committee, recently under the chairmanship of John Lee Olsen. His report showed several interesting trends. The number of newly graduated chemical engineers applying for membership through September of their year of graduation is now 15%, almost double that of 1951. Philadelphia-Wilmington Section was a shade ahead of South Texas in number of applications submitted, a reversal of the positions of last year. Maine led however in the ratio of present members to applications submitted - 23%.

Ohio State led the colleges in number of students submitting applications, 22 out of a graduating class of 29 - a percentage of 76. Montana State was next with 71%, and Northwestern Tech came third with 65%.

Membership figures were also predicted by the committee during the year. Estimate for 1960, 22,000 in the A.I.Ch.E. Committee chairmanship is now with J. W. Schall of Houdry.

<u>Sadly</u> note was taken of the death of Jack Perry, and in its resolution Council said, "The passing of John H. Perry . . . removed from the membership . . . a valued and respected member. . . . Throughout the entire thirty years of his membership he gave freely of his time in furthering [our] aims and purposes . . . he served as director . . . on many of the important committees . . . and the Institute wishes to recognize and express its appreciation of the many contributions which he has made to the profession of chemical engineering, particularly in acting as editor of the "Chemical Engineers' Handbook." . . . Council . . . records with a sense of loss and sorrow, his passing. . . ."

— As we do on the magazine, and salute him with the traditional editorial ending

-- 30 --   F.J.V.A.